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No. 450-90G-TR-0003

NAVAL SEA SYSTEMS COMMAND INTEGRATED ROBOTICS PROGRAM

ANNUAL REPORT
FISCAL YEAR 1985

DECEMBER 1985

OFFICE OF ROBOTICS AND AUTONOMOUS SYSTEMS
SEA 90G
NAVAL SEA SYSTEMS COMMAND
WASHINGTON, D.C. 20362-5101

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This is a four section report consisting of text and graphics. Section I; discusses the opportunity that robotics offer Navy (NAVSEA) and the approach that is being followed to achieve an integrated program; establishes the need and the overall goals and basic objectives of the program; and highlights significant accomplishments. Section II reports on the scope, progress, and status of the key projects being pursued under the integrated program umbrella. Section III addresses the importance of conducting (over)

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thorough technology assessments to establish a baseline for further development of applications of robotic technology. Section IV summarizes progress made in FY 85, presents a prognosis, reports on lessons learned, discusses concerns, and concludes with an identification of the key FY 86 planning objectives and out-year planning initiatives. The report contains a schematic depiction of the structural program for technology assessment, application studies, focused research and development and demonstration projects, and a broadly time-lined planning scenario, and continues with a comprehensive matrix of all project work, grouped by functional area, which identifies the NAVSEA code sponsor/project manager/performing organization relationships. It also includes the names, locations and electronic mailing addresses of all key personnel involved in this centrally coordinated, decentrally executed program.

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LCDR H. R. EVERETT, USN
DIRECTOR

OFFICE OF ROBOTICS AND AUTONOMOUS SYSTEMS
SEA 90G
NAVAL SEA SYSTEMS COMMAND
WASHINGTON, D.C. 20362-5101

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NAVAL SEA SYSTEMS COMMAND
WASHINGTON, DC 20362-5101

PREFACE

The Naval Sea Systems Command (NAVSEA) has undertaken a Command-wide effort to conceptualize, develop, and implement an Integrated Robotics Program. This work was initiated early in FY 83 by COMNAVSEA, Vice Admiral E. B. Fowler, when he established, within the NAVSEA Acquisition, Planning and Appraisal Directorate, a billet for a Special Assistant for Robotics to serve as the focal point of NAVSEA interest. LCDR H. R. (Bart) Everett has served in this billet since its inception.

The Office of Robotics and Autonomous Systems (SEA 90G) was officially established, under LCDR Everett, in May 1984. COMNAVSEA's interest in and commitment to robotics was confirmed and expanded by issuance in FY 84 of a broad policy statement that constituted the formal start of and guidance for the integrated program described in this document.

This FY 85 Annual Report consists of four sections, with content as follows:

Section I - INTRODUCTION discusses the potential opportunities to the Navy and the approach being followed to achieve an integrated robotics program; establishes the need and overall goals and basic objectives of the program; reflects the program's chronological history; and highlights some accomplishments to date.

Section II - PROJECT REVIEW reports on the scope, progress and status of projects being pursued. A matrix index of all ongoing projects is included at the back of this volume, with NAVSEA and performing organization points of contact.

Section III - TECHNOLOGY CONCERNS discusses the importance of identifying supporting technology voids, lists specific areas of needed research and development, and describes mechanisms for technology transfer.

Section IV - SUMMARY, CONCLUSIONS AND PROJECTIONS appraises the end-of-year status of the program and its future evolution and objectives.

DEPARTMENT OF THE NAVY

NAVAL SEA SYSTEMS COMMAND

WASHINGTON, D.C. 20362

IN REPLY REFER TO
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11 May 1984

From: Commander, Naval Sea Systems Command
To: Distribution

Subj: NAVSEA POLICY RELATIVE TO INTELLIGENT MACHINE AUTOMATION AND ROBOTICS

1. Intelligent Machine Automation is a new area of advanced technology being extensively researched, developed and applied within industry. As a multi-billion dollar claimant of the industrial resources of the nation, the Navy must capitalize on the tremendous potential of this new technology in the manufacture, maintenance and operation of ship and combat systems when it is cost effective to do so. In this regard, an important goal of this Command is to ensure that the Navy utilizes intelligent systems to reduce total life-cycle costs, guarantee quality, improve readiness, extend endurance, free human assets for higher-order functions, and enhance the attractiveness of shipboard life for Naval personnel.

2. It is recognized that all parts of such a comprehensive goal cannot be achieved simultaneously, but because they are interrelated they should be pursued on an integrated basis. A NAVSEA Robotics Program Plan (under development) will set forth the planned actions to achieve this integration. In the interim, addressees are encouraged to investigate ways to utilize this new technology to improve quality and productivity in their functional areas.

3. The Robotics Program Plan, which will reflect the deliberations and the earlier independent work of the members of the NAVSEA Robotics Council, will fully develop the following approach: establish an understanding and Command awareness of the state-of-the-art and the current prognosis for robotics/Intelligent Machine Automation technology; accumulate and organize a readily accessible data base; critically and constructively review all ongoing projects and ensure that continuing efforts in those projects are addressed to accomplishments consistent with the major thrusts comprising the Command goal; identify Navy needs for robotic applications; match those needs to technology requirements; address through research and development efforts those technology requirements that are not being addressed by the private sector; share technology across as broad a commercial and Navy spectrum as is feasible; develop and demonstrate prototype applications; conduct cost benefit analyses on all promising prototypes; select and implement winners; and, sponsor an appreciation of the robotic power of proven prototypes throughout the Navy.

4. To facilitate the attainment of this goal, LCDR Bart Everett (SEA 90G) is designated as my Special Assistant for Robotics. He will be responsible for developing and executing the Robotics Program Plan; acquiring, synthesizing and disseminating robotics technological information; conducting studies, convening workshops and attending industrial and academic conferences and demonstrations; and participating as a counselor/advisor to NAVSEA in exploratory and decision briefings related to robotics applications in ship and weapon acquisitions, maintenance and operational programs.

5. To minimize redundancy in development efforts, to ensure the compatibility of independently developed systems, to avoid the risks of inappropriately assigned or ill-conceived applications, and to ensure that progress is made on the broad spectrum of the Robotics Program Plan (when promulgated), all NAVSEA robotics efforts shall be coordinated with SEA 90G.

6. The NAVSEA Robotics/Artificial Intelligence Data Base has been established at the Naval Oceans Systems Center to provide the mechanism for descriptive and status information on all ongoing and planned robotics projects. Individual codes initiating programs in robotics are tasked to become aware of and take advantage of ongoing and planned efforts, and to ensure that new initiatives are properly scoped to provide the maximum advantage to the Command.

7. All of the foregoing is intended to provide a Command atmosphere of acceptance for initiatives in this important new technology. I call upon all of you to examine the opportunities that robotics offers to your functional responsibilities, and to consider the allocation of some of your resources in appropriate projects as an investment in the Navy's future.

E. B. Fowler
E. B. FOWLER

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SECTION I - INTRODUCTION

THIS SECTION PRESENTS THE PHILOSOPHY, CONCEPT, AND STRUCTURE THAT SERVE AS THE UNDERPINNINGS FOR THE DECISION TO INTEGRATE THE PROGRAM, AND HIGHLIGHTS THE ACCOMPLISHMENTS TO DATE, UNDER THESE HEADINGS:

- THE OPPORTUNITY
- THE NEED FOR AN INTEGRATED PROGRAM
- THE APPROACH
- PROGRAM GOALS AND OBJECTIVES
- ACCOMPLISHMENT HIGHLIGHTS

INTRODUCTION

THE OPPORTUNITY

We are in an environment which demands more efficiency and increased productivity in order to protect important national defense programs such as the 600-ship Navy. The drive to reduce the budget deficit to the zero level by 1991 clearly challenges all managers to seek innovative techniques to increase productivity and maintain planned high quality output while reducing costs.

In his annual report to Congress, Richard D. DeLauer, former Under Secretary of Defense for Research and Engineering, indicated that life science and robotics/machine intelligence rank high on the list of basic technologies with the greatest potential for significantly improving capabilities in the next 10 to 20 years. Robotics/machine intelligence is a new outgrowth of advanced technology that is being extensively researched and applied in industry to effect increases in productivity, improve resultant quality, and enhance worker safety and comfort. The industrial robots available today are the result of the merging of significant technical advances in electrical and mechanical engineering, as well as in computer science. Until recently, robots were complex and expensive machines justifiable only in high-volume applications. Continuing improvements in technology have decreased the price of componentry and broadened the range of cost-effective usage.

The projected major impact of future robotic systems on potential Navy applications is based soundly on these continued technological improvements and cost reductions, coupled with recognition that there will be many advantages over the human labor counterpart. Multi-functional flexible systems with ever-improving dexterity and adaptability can perform tasks requiring constant attention to detail (oblivious to chemical, nuclear, or industrial environments harmful or unpleasant to humans) with great repetitiveness and minimal downtime. By virtue of these characteristics, such systems can markedly reduce the need for specialized labor and extensive personnel training programs, and can contribute significantly to gains in productivity as well as quality.

The prospective development of appropriate sensors and intelligent systems has made real-time adaptive control of the robot's actions a reasonable expectation in the near future. Coupled with sophisticated off-line programming techniques and knowledge-based control concepts, these developments are rapidly expanding the range of potential applications for industrial robots into the medium- and low-volume regions typical of ship construction and repair scenarios. The Navy, with its multibillion-dollar industrial base, stands to benefit enormously.

THE OPPORTUNITY

- THE CHALLENGE IS TO REDUCE COSTS IN:
  - SHIP AND WEAPON SYSTEM ACQUISITION
  - REPAIR AND OVERHAUL WORK

- AND ... REDUCE THE MANNING REQUIREMENTS OF A 600-SHIP NAVY

- A SUPPORTING INFRASTRUCTURE IS AVAILABLE TO TRANSLATE NEW DEVELOPMENTS INTO:
  - SHIPBUILDING TECHNOLOGY
  - WEAPONS MANUFACTURING
  - MAINTENANCE AND REPAIR
  - SHIPBOARD AND OTHER MOBILE SYSTEM APPLICATIONS
  - INTELLIGENT WEAPONS
  - AUTONOMOUS SYSTEMS

- MANPOWER IMPLICATIONS:
  - REDUCED NEED FOR SPECIALIZED LABOR AND TRAINING
  - BETTER AND SAFER USE OF HUMAN ASSETS
  - POSSIBLE DECREASE IN TOTAL MANNING REQUIREMENTS

- INCREASED PRODUCTIVITY THROUGH:
  - AN INCREASING NUMBER OF POTENTIAL APPLICATIONS
  - AN IMPROVING COST TO CAPABILITY RATIO
  - USE OF ADAPTIVE CONTROL IN UNSTRUCTURED ENVIRONMENTS
  - INTANGIBLE BENEFITS

INTRODUCTION

THE NEED FOR AN INTEGRATED PROGRAM

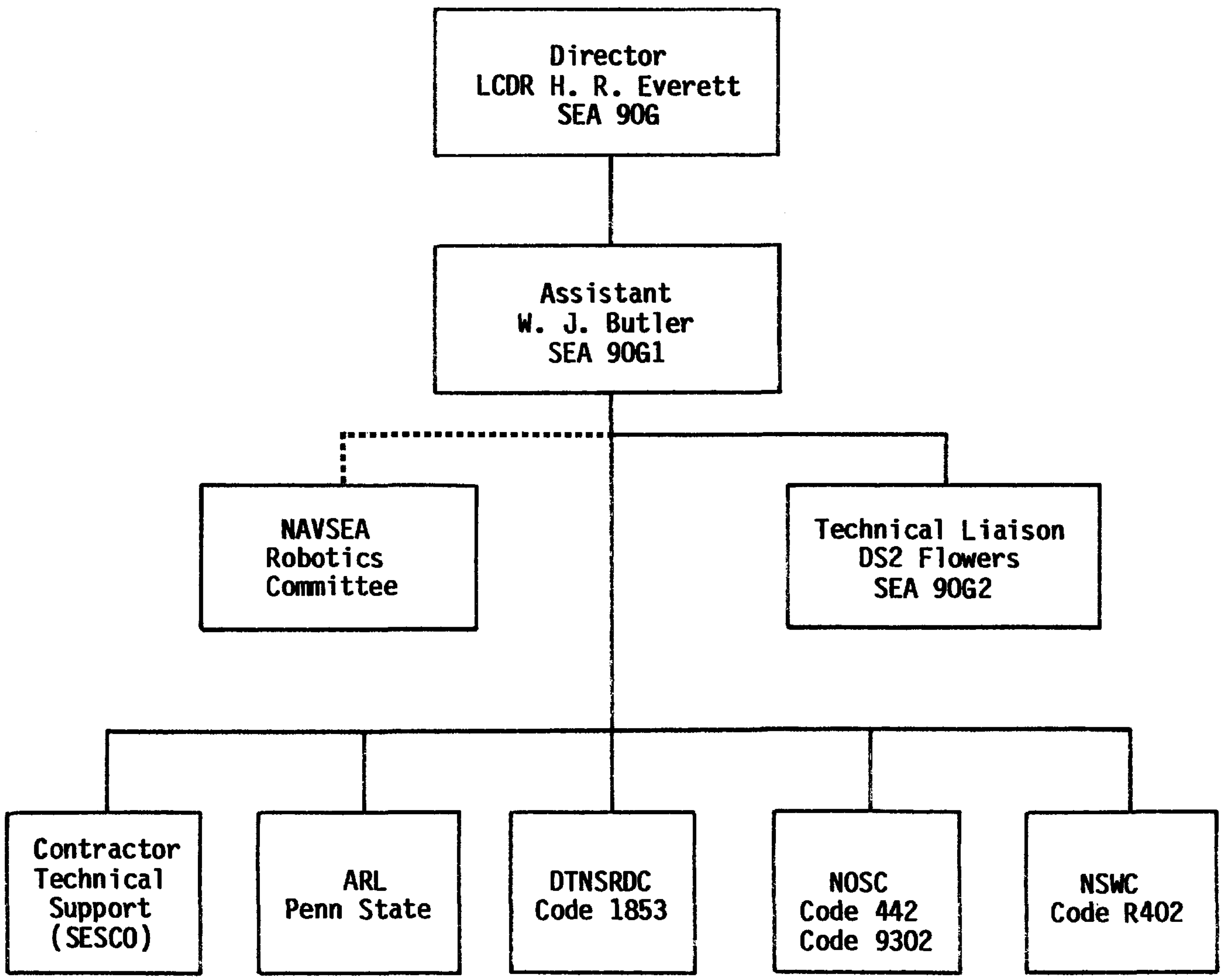
Under pressure to reduce costs and increase productivity while establishing and maintaining an effective 600-ship force at a high state of readiness, the Navy must seek out and apply relevant innovative technology. Technological progress is one of the most powerful forces in the effort to improve upon conventional practices associated with the manufacture, repair, and operation of ship systems. Transforming new concepts into practical and productive use is not guaranteed. Reaping the benefits of robotic technology requires a well organized program with realistic short and long term goals. For such technology to be useful, it must be accessible, timely and appropriate. An aggressive and directed integrated NAVSEA program, with participation at all levels, is essential to effectively capitalize on the perceived benefits of flexible automation and intelligent systems.

Recognizing the need to rapidly transition this evolving technology into productive use, NAVSEA initiated its Integrated Robotics Program in 1984. Considerable effort had been expended toward development of industrial robotic capabilities using Manufacturing Technology (MT) Program funds, with significant results. The scope of support must expand, however, as efforts to reduce costs and improve efficiency and services through technical advances continue to intensify. The growing sophistication of products and processes underscores the need for increased funding, communications, cooperation, and technology transfer.

The overall integrated program is characterized by the need to: identify technology deficiencies and applications; match requirements to capabilities; identify appropriate research, development, and demonstration projects; minimize redundancies; update the technology baseline; initiate Navy sponsored research for unique Navy requirements; and accomplish technology transfer.

A critical need of an integrated program is NAVSEA's awareness of research and development efforts sponsored and funded by other commands. An effective NAVSEA/ONR/ONT interrelationship is essential for ensuring maximum progress and cost-effective results. Separately managed efforts within NAVSEA must be linked via the integrated NAVSEA program to minimize difficulties in meeting projected milestones, and ensure optimal utilization of limited resources.

OFFICE OF ROBOTICS AND AUTONOMOUS SYSTEMS



SEA 90G ORGANIZATION AND SUPPORTING INFRASTRUCTURE

INTRODUCTION

THE APPROACH

The NAVSEA Integrated Robotics Program is being built on the foundation created by earlier independent studies and projects. It is necessary to continually assess the status of ongoing work and establish a close working bond between participants. An overall awareness of the totality of activity is maintained through visits to the Naval Laboratories and Centers where the research is being managed, and to the universities and private sector contractors performing the work.

SEA 90G has developed a four-part approach for coordinating and providing technical support to robotics efforts within NAVSEA:

First- The participants define, develop, and share a robotics technology baseline so research efforts do not address technical requirements already being researched or completed.

Second- A concerted effort is made to develop within the Command an appreciation of the value of flexible automation and intelligent systems to the future Navy, and to provide a mechanism to facilitate application conceptualization.

Third- A disciplined methodology is developed and implemented progressively within the Command for (a) determining user-oriented requirements through application studies and surveys, (b) matching those requirements to the capabilities of available technology, (c) developing and testing prototypes of pay-off promising applications when requirements and technology are appropriately matched, (d) funding/conducting advanced research and development efforts where private sector initiatives are not addressing identified needs, (e) conducting credible cost benefit analyses of alternative prototype solutions to approved applications, and (f) establishing controls to minimize redundancy, ensure compatibility, and avoid wrongly assigned or poorly conceived application projects.

Fourth- The NAVSEA Robotics Committee is established with representation from NAVSEA functional codes and Navy Laboratories and Centers, functioning together under the Chairmanship of SEA 90G. The Committee is an integrated body of engineering, scientific and management professionals organized to interchange knowledge of robotic technology as a means for fostering its prudent use in Naval applications, and to assist in execution of the NAVSEA Integrated Robotics Program.

THE APPROACH

- THE NAVSEA INTEGRATED ROBOTICS PROGRAM IS BASED ON A FOUNDATION OF INDEPENDENT STUDIES AND PROJECTS

- PARTICIPANTS DEFINE, DEVELOP, AND SHARE THE ROBOTICS TECHNOLOGY BASELINE

- DEVELOP AWARENESS OF ROBOTICS:
  - APPRECIATION OF VALUE TO FUTURE NAVY
  - RECOGNITION OF TECHNOLOGY DEFICIENCIES AND LIMITATIONS
  - FACILITATE APPROPRIATE APPLICATION

- IMPLEMENT A DISCIPLINED METHODOLOGY:
  - APPLICATION STUDIES TO DETERMINE USER ORIENTED REQUIREMENTS
  - MATCH REQUIREMENTS TO CAPABILITIES OF AVAILABLE TECHNOLOGY
  - DEVELOP AND TEST PROTOTYPES
  - ADVANCED RESEARCH FOR UNIQUE NAVY NEEDS
  - COST BENEFIT ANALYSIS OF ALTERNATIVES
  - CONTROLS TO MINIMIZE REDUNDANCY AND ENSURE COMPATIBILITY

- ESTABLISH NAVSEA ROBOTICS COMMITTEE:
  - COMPOSED OF ENGINEERING, SCIENTIFIC, AND MANAGEMENT PROFESSIONALS
  - FOSTER PRUDENT USE OF ROBOTIC TECHNOLOGY
  - ASSISTS IN EXECUTION OF NAVSEA INTEGRATED ROBOTICS PROGRAM

INTRODUCTION

PROGRAM GOALS AND OBJECTIVES

The NAVSEA Integrated Robotics Program acquires its basic structure from the goals and subgoals, its direction and thrust from the program objectives, and its measurable specificity for performance from individual project objectives.

The NAVSEA goal in these premises is mission oriented in the broad sense, and relatively timeless in that it states a direction for action to be taken, without setting specific limits on when the destination must be reached, and without prescribing the route to take to achieve the goal.

Although the program objectives are also broadly worded, they serve to scope the activity appropriate for the program and to set expectations for results. Subgoals facilitate program management by adding a degree of specificity to the classification of the work. Projects, in turn, are organized under subgoals. Each project has its own discrete objectives seeking to contribute to the larger objective of the appropriate subgoal. Project objectives must be clearly drawn to produce measurable results. When all projects under any subgoal have been completed, the objectives of the subgoal will have been achieved. Similarly, when all subgoals have been completed, the program goal will have been reached. It is possible, however, that program developments, unforeseen at the outset, may dictate the articulation/establishment of additional subgoals, each with its own projects.

By pursuing the program goal and objectives, NAVSEA expects to improve productivity and quality, reduce costs, increase efficiency and improve the quality of life aboard ships and throughout the Navy community. The explosion in new technology coupled with the problems of assimilating and implementing available technology underscore the need for a focused structured approach to establishing and achieving these goals and objectives. Appropriate applications of available robotic technology and timely development of capabilities to fill identified needs offer great potential for enhancing and protecting the quality and performance of ships and their associated weapons systems.

PROGRAM GOALS AND OBJECTIVES

PROGRAM GOAL

To ensure that the Navy of the next century uses the robotics technology that will be available to improve the quality and performance of Navy ships and weapons systems; reduce acquisition, repair, and overhaul costs; and improve readiness and endurance, while freeing human assets for higher order functions

PROGRAM OBJECTIVES

To ensure the orderly and timely introduction of robotics into

- Shipbuilding and weapons manufacturing
- Repair and maintenance
- Operations

To reduce costs, increase effectiveness, and enhance safety and health

SUBGOAL A
COMMAND READINESS

To attain, maintain, and share a current Navy/NAVSEA in-house knowledge and appreciation of state-of-the-art robotic technology and to develop expertise in its use and management

PROJECT A-1

A-2

A-n

SUBGOAL B
APPLICATION STUDIES

To establish a comprehensive inventory of Navy needs for robotic applications and to establish and maintain a current feasibility and cost benefit relationship between Navy needs and emerging robotic technology projected over the time frame of the needs

PROJECT B-1

B-2

B-n

SUBGOAL C
TECHNOLOGY DEVELOPMENT

To select, develop, test, and implement robotic applications on a continuing annual operating plan basis representing best-judgment decisions reflecting an integration of needs, costs, and technological risk assessment

PROJECT C-1

C-2

C-n

ACCOMPLISHMENT HIGHLIGHTS

Building on the organizational and programmatic structure established during FY 84, the NAVSEA Integrated Robotics Program has made significant strides in this past year. The scope and number of ongoing NAVSEA projects identified during FY 85 has shown noticeable expansion in the areas of shipbuilding and weapons manufacturing, repair, and operations. A continuing dialogue has been established with sponsors and project leaders in an effort to elevate awareness of the potential of intelligent system applications in the Navy. FY 85 was characterized by numerous technical assessments of ongoing NAVSEA projects, an orchestrated program to raise the level of Command awareness, and further development of mechanisms for technical review and technology transfer. Recognizing the growing responsibilities and increased involvement of the Robotics Program, COMNAVSEA authorized the establishment of an additional support billet (SEA 90G1) at the GM-13 level.

During FY 85, over 65 ongoing NAVSEA projects were identified, primarily in the functional areas of welding, metal working, propeller manufacturing, surface preparation, materials handling, explosive ordnance disposal, underwater systems, firefighting and security. Section II of this report contains descriptive summaries of these projects. Positive actions have been taken to strengthen, modify, or redirect efforts as a result of project reviews, technology demonstrations, and technology transfer.

Selected examples of major project work during FY 85 include the Integrated Computer-Aided Manufacturing of Propellers (ICAMP) project, the Integrated Flexible Welding System (IFWS), the Laser Articulated Robotic System (LARS), the Intelligent Robotics Inspection System (IRIS), and efforts in explosive ordnance disposal and underwater applications.

In addition to communicating and advocating its approach to an integrated effort within NAVSEA, SEA 90G briefed, on request, a number of external activities on the scope, content, status and direction of the NAVSEA Integrated Robotics Program, including:

Naval Studies Board of the National Academy of Sciences - NAVSEA project managers gave a comprehensive briefing to the Robotics Exploratory group, under the auspices of SEA 90G.

Office of Research, Development, Test and Evaluation (OP 098) - SEA 90G presented a full-scale technical and programmatic briefing, emphasizing projected areas of concern.

Office of Naval Research - Briefing to ONR staff for purposes of explaining and offering RAID as a mechanism for tracking research and development projects in robotics and artificial intelligence throughout DoD.

ACCOMPLISHMENT HIGHLIGHTS

- SIGNIFICANT EXPANSION OF EFFORTS IN FY 85:
  - OVER 65 IDENTIFIED NAVSEA DEVELOPMENT EFFORTS
  - CONTINUING DIALOGUE WITH SPONSORS AND PROJECT LEADERS
  - TECHNICAL REVIEWS OF ONGOING NAVSEA EFFORTS
  - INCREASED THE AWARENESS OF TECHNOLOGICAL NEEDS
  - PURSUED IDENTIFICATION OF:
    - PRACTICAL APPLICATIONS
    - TECHNOLOGY DEFICIENCIES
  - DEVELOPMENT OF MECHANISMS FOR TECHNICAL REVIEW AND TECHNOLOGY TRANSFER

- FUNCTIONAL AREAS OF EMPHASIS IN FY 85:
  - WELDING
  - METAL WORKING
  - PROPELLER MANUFACTURING
  - SURFACE PREPARATION
  - MATERIALS HANDLING
  - EXPLOSIVE ORDNANCE DISPOSAL
  - UNDERWATER SYSTEMS
  - FIREFIGHTING
  - SECURITY

ACCOMPLISHMENT HIGHLIGHTS (Continued)

Office of Naval Research/Office of Naval Technology - A selected project briefing to identify technology voids and areas of needed research, and present a strategy for acquiring the necessary technology base to proceed with advanced and engineering development of robotic applications.

The expanded activity generated by the growing number of NAVSEA projects demanded an increase in the need to conduct technical assessments. A valuable source of technical support was the Robotics Committee and its associated working groups. Specific project reviews were conducted for the Robot Assisted Surface Preparation and Paint (RASPP), Laser Articulated Robotics System (LARS), Three-Dimensional Weld Seam Tracking System (3D-WSTS), Robotic Adaptive Welding System (RAWS), Composite Hull Advanced Manufacturing Process (CHAMP), Robotic Structural Shapes Processing System, Deep Submergence Vehicle Manipulator Arm, and the DNA Robotics for Physical Security Program.

Robotics Committee - Based on its outstanding performance as an informal, volunteer group, COMNAVSEA authorized the formalization of this body and directed a charter be prepared to govern its activities.

For conducting the detailed work of the Robotics Committee, three Working Groups (WG) were functional in FY 85:

- Welding Applications WG: To research and recommend welding applications appropriate for RAWS and LARS implementation.

- RASPP Review WG: To conduct a comprehensive examination of the RASPP Phase I feasibility report.

- Charter Preparation WG: To develop the charter for formalization of the Robotics Committee.

In this year of transition, emphasis has been on developing broad support for the program. The importance of Command awareness, technology assessment and project review, identification of robotics technology applications and deficiencies, the organization and accumulation of an effective database, and enhancement of technology transfer have all been key efforts in the expanding program.

ACCOMPLISHMENT HIGHLIGHTS

- SELECTED EXAMPLES OF MAJOR PROJECT WORK AND PROJECT REVIEWS:

  - ROBOT ASSISTED SURFACE PREPARATION AND PAINT (RASPP)
  - INTEGRATED FLEXIBLE WELDING SYSTEM (IFWS)
  - LASER ARTICULATED ROBOTIC SYSTEM (LARS)
  - INTELLIGENT ROBOTIC INSPECTION SYSTEM (IRIS)
  - 3-D WELD SEAM TRACKING SYSTEM (3D-WSTS)
  - ROBOTIC ADAPTIVE WELDING SYSTEM (RAWS)
  - COMPOSITE HULL ADVANCED MANUFACTURING PROCESS (CHAMP)
  - ROBOTIC STRUCTURAL SHAPES PROCESSING SYSTEM
  - EXPLOSIVE ORDNANCE DISPOSAL (EOD)
  - DEEP SUBMERGENCE VEHICLE MANIPULATOR ARM
  - DNA ROBOTICS FOR PHYSICAL SECURITY PROGRAM

- BRIEFINGS:

  - NAVAL STUDIES BOARD OF THE NATIONAL ACADEMY OF SCIENCES
  - OFFICE OF RESEARCH, DEVELOPMENT, TEST AND EVALUATION
  - OFFICE OF NAVAL RESEARCH
  - OFFICE OF NAVAL TECHNOLOGY

- INCREASED NAVSEA ROBOTICS COMMITTEE ACTIVITY:

  - NUMEROUS TECHNOLOGY ASSESSMENTS
  - VALUABLE ENGINEERING AND SCIENTIFIC SUPPORT
  - ACTIVE WORKING GROUPS
    -- WELDING APPLICATIONS WORKING GROUP
    -- RASPP WORKING GROUP
    -- CHARTER PREPARATION WORKING GROUP
  - FORMALIZATION OF COMMITTEE CHARTER

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SECTION II - PROJECT REVIEW

THIS SECTION PRESENTS BRIEF DESCRIPTIONS OF THE PROJECTS THAT MAKE UP THE NAVSEA INTEGRATED ROBOTICS PROGRAM. THE SUMMARIES ARE BASED ON TECHNICAL REVIEWS CONDUCTED BY THE ROBOTICS COMMITTEE AS WELL AS REPORTS SUBMITTED BY AND DISCUSSIONS WITH THE PROJECT MANAGERS. A MATRIX INDEX OF THESE PROJECTS AND PERFORMING ACTIVITIES IS INCLUDED AT THE END OF THIS VOLUME.

THE PROJECTS ARE PRESENTED UNDER THREE GENERAL AREAS:

- SHIPBUILDING AND WEAPONS MANUFACTURING
- REPAIR AND MAINTENANCE
- OPERATIONS

THE PROJECTS SUMMARIZED IN THIS SECTION REPRESENT CONTINUED PROGRESS TOWARD THE GOAL OF ENSURING THE TIMELY AND ORDERLY INTRODUCTION OF ROBOTICS INTO THE NAVY.

NAVSEA MANUFACTURING TECHNOLOGY PROGRAM

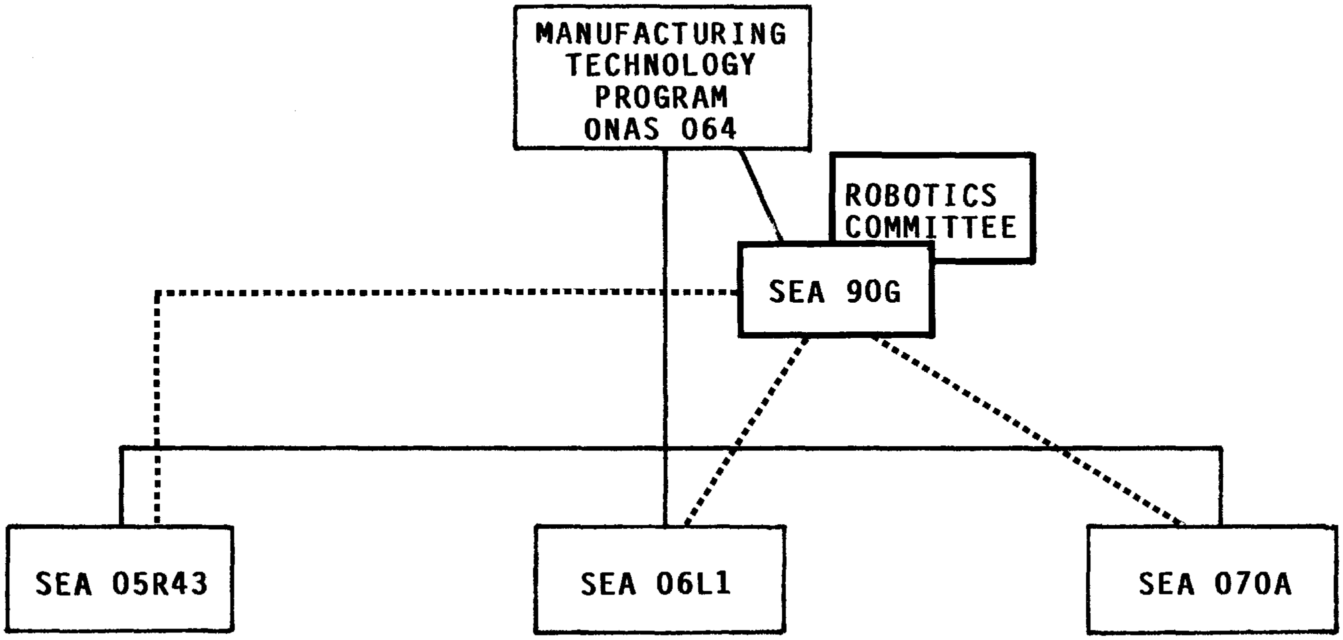
The Navy Manufacturing Technology (MT) Program, directed by Jack McInnis (ONAS 064), is a principal enabling resource driving the development and implementation of flexible automation within both naval and private shipyards. The MT Program is, in general, a mechanism to provide for the infusion of high technology into naval shipyards and the production facilities of Navy contractors. By so doing, the program realizes improvements in cost, quality, and schedule on Navy system acquisitions and overhauls. Among other things, the program has been largely responsible for development of sensor and processing capabilities needed for the adaptation of commercially available welding robots to Navy needs.

A well managed program can result in a reduction in life cycle costs, an acceleration from R&D to implementation, the establishment of improved processes, methods, techniques and equipments, and maximum transfer of technology. Within NAVSEA, MT projects are managed by three separate offices: SEA 05R43 manages shipbuilding and systems-related projects; SEA 06L1 manages projects related to weapons manufacturing; and the repair and maintenance functions of naval shipyards and related industrial facilities are managed by SEA 070A. SEA 90G, with support from the Robotics Committee, provides technical review and program integration functions for robotics-related efforts.

The application of state-of-the-art technologies is vital to the objective of enhancing fleet readiness through increased productivity and reduced life cycle costs. MT efforts must be identified with a well-defined Navy application, demonstrate technical feasibility, and lead to timely implementation.

Much of the MT effort has focused on robotic welding, because applications studies indicate this to be a productive area for short-term investment. The studies and subsequent analysis by NAVSEA indicated the greatest barrier to cost-effective use by the Navy is the inability to adapt commercially available robotic welding systems to variations or changes in joint geometry brought on by thermal expansion, poor initial fit-up, or other variables associated with the welding process. This situation is compounded by the small lot sizes encountered in a typical Navy environment. A systematic review of all ongoing welding-related projects sponsored by NAVSEA identified several efforts that addressed areas associated with gas metal arc and laser welding.

NAVSEA MANUFACTURING TECHNOLOGY PROGRAM STRUCTURE
FOR ROBOTICS



- PROGRAM OBJECTIVES:
  - REDUCE AQUISITION AND LIFE CYCLE COSTS
  - INCREASE PRODUCTIVITY
  - MAXIMIZE TECHNOLOGY TRANSFER
  - STRENGTHEN THE INDUSTRIAL BASE
- MT CRITERIA:
  - ESTABLISH A UNIQUE NAVY NEED
  - DEFINE THE APPLICATION
  - DEMONSTRATE TECHNICAL FEASIBILITY
  - ENSURE TIMELY IMPLEMENTATION
- ROBOTIC WELDING IS A PRODUCTIVE AREA FOR SHORT-TERM INVESTMENT
- SENSOR DEVELOPMENT AND PROCESSING CAPABILITIES ARE NEEDED TO ADAPT COMMERCIAL ROBOTS TO NAVY NEEDS

INTEGRATED FLEXIBLE WELDING SYSTEM

Overview

The complexity of Naval ship systems, the massive size of ship components, and the low volumes and unstructured environments encountered present unique obstacles to the application of robotic technology to shipbuilding and repair scenarios. Accordingly, the Integrated Flexible Welding System (IFWS) seeks to develop an adaptive Gas Metal Arc Welding (GMAW) robotic installation for operation in a shipyard environment, capable of making high-quality, cost-effective welds for single and small batch workpieces. The IFWS philosophy features a modular development approach (to allow the pursuit of quasi-independent efforts), with emphasis on the generic nature and characteristics of the modules. This evolutionary approach allows for near-term payoff generated by the implementation of individual modules, which effectively reduces the cost of the overall system. Individual modules can be replaced or upgraded as a technology evolves or as an approach fails, thereby preventing system obsolescence.

The IFWS conceptual design envisions an adaptive GMAW robot, coupled with modular sensors for seam tracking, collision avoidance, workpiece orientation, and real-time process control. These will be integrated through a knowledge-based, distributed control hierarchy that will interpret computer-aided-design (CAD) input, plan the weld, provide off-line programming for robot movement, specify control parameters, and interpret and provide corrections based on real-time sensor feedback.

Because of reduced funding allocations for FY 86, the IFWS system development schedule has been revised, resulting in the suspension of a few componentry projects such as the Global Vision System. The projects with sufficient funding are continuing on a modified schedule structured around the technology voids left by the suspended efforts. It is essential to the integrity of the IFWS concept that those projects currently without money remain within the overall project envelope -- even as development is deferred -- while additional funds are actively pursued. These actions are designed to maintain the structure and objectives of the IFWS philosophy, to ensure ongoing development efforts generate applicable short-term results, and to prove enough flexibility resides within the approved approach to adjust to funding fluctuations.

INTEGRATED FLEXIBLE WELDING SYSTEM OVERVIEW

- PROBLEM: APPLICATION OF ROBOTICS TECHNOLOGY TO NAVAL SHIPBUILDING AND REPAIR HINDERED BY COMPLEX, UNSTRUCTURED SHIPYARD ENVIRONMENT

- OBJECTIVE: TO DEVELOP AN ADAPTIVE WELDING WORKCELL FOR HIGH-QUALITY, COST-EFFECTIVE WELDS ON SMALL BATCH WORKPIECES

- APPROACH: TO DEVELOP A MODULAR DESIGN PERMITTING DECENTRALIZED DEVELOPMENT OF WORKCELL COMPONENTS AND CENTRALIZED COMPONENT INTEGRATION, RESULTING IN AN EVOLUTIONARY APPROACH WHICH GENERATES NEAR-TERM PAYOFFS AND LOWER COSTS, WHILE PREVENTING SYSTEM OBSOLESCENCE

- COMPONENT EFFORTS:
  - ROBOTIC ADAPTIVE WELDING SYSTEM (SEA 070A)
  - 3-D WELD SEAM TRACKING SYSTEM (SEA 070A)
  - GLOBAL VISION SYSTEM (NSWC)
  - INTELLIGENT COMMUNICATION INTERFACES (NOSC)
  - OVERALL ARCHITECTURE (NOSC)

- STATUS: REDUCED FUNDING HAS REQUIRED THE RESTRUCTURING OF INDIVIDUAL PROJECTS:
  - DEVELOPMENT SCHEDULE REVISED WITH CERTAIN PROJECTS DEFERRED
  - SHORT TERM EFFORTS CONSISTENT WITH IFWS CONCEPT AND LONG RANGE OBJECTIVE

INTEGRATED FLEXIBLE WELDING SYSTEM

System Architecture

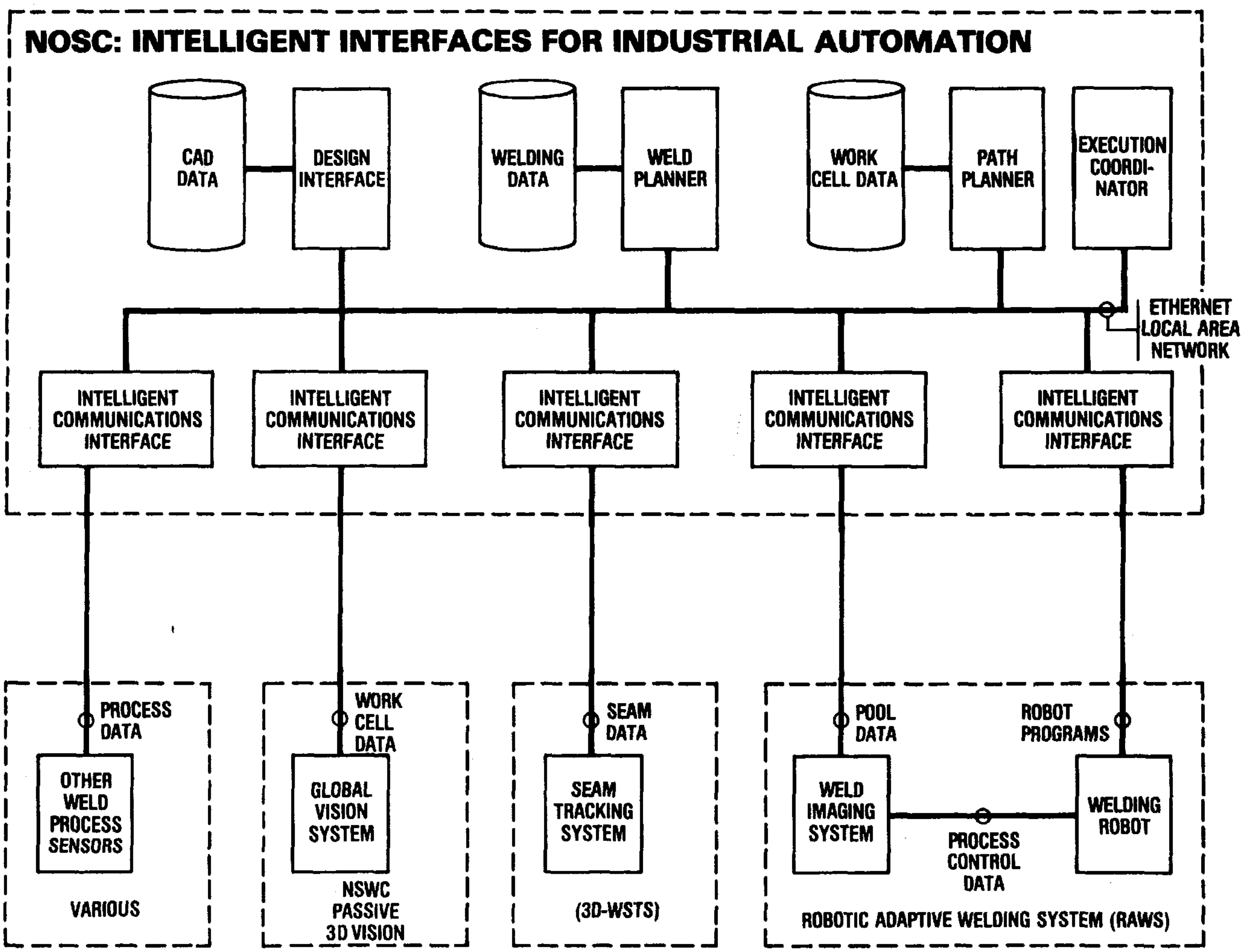
In order to achieve effective implementation of the IFWS concept, the control system must overcome integration problems inherent in a multi-component automated workcell. Accordingly, a significant effort has been undertaken to develop a powerful control structure common to all components. The resulting IFWS Architecture (developed by NOSC), shown on the facing page, illustrates the modular development approach being taken by NAVSEA.

The basic computing structure of the IFWS architecture separates the computationally-slow planning processes from the real-time sensor and control operations, i.e., the planning of work functions takes place off-line, while the activation of these functions occurs on-line, with the knowledge-based components maintaining only a supervisory role. This partitioning between planning and functional aspects of the system is made possible because much is known for certain about the environment and task. Therefore, any deviations from the planned sequence of events should be limited and easily correctable by supervisory processes.

The upper level of the hierarchical architecture consists of knowledge-based planning and control components which include a design interface, a weld planner, a path planner, and an execution coordinator. The lower level consists of the specific sensor, control, and hardware subsystems which interact with the workcell environment. Linking these two levels together is a series of Intelligent Communication Interfaces (ICI), with one interface corresponding to each low-level subsystem. The ICI is a generic interface protocol developed by NOSC. Communications between all components are carried by an Ethernet local area network (LAN).

The design interface component of the knowledge-based subsystem is a computer-aided-design workstation through which the user will have access to the entire IFWS operation. As the major input/output device and "window" into the system, the workstation provides specific services to the design engineer, the shop floor manager, and the systems programmer. Utilizing the CAD databases, geometric modelers, and application-specific expert systems provided, the design or weld engineer is able to construct a solid model of the desired part and represent the specifics of the weld process necessary for the workpiece model. Once completed, the model and its associated weld process are distributed for use during the planning phase. Furthermore, shop floor personnel are able to monitor, set-up, and maintain the system through the design interface. The interface provides system programmers access to the internal data processing functions for system debugging and modification.

INTEGRATED FLEXIBLE WELDING SYSTEM ARCHITECTURE



THE IFWS ARCHITECTURE, DEVELOPED AT THE NAVAL OCEAN SYSTEMS CENTER (NOSC), PRESENTS A MODULAR APPROACH TO THE SYSTEMS INTEGRATION PROBLEMS INHERENT IN MULTI-COMPONENT, AUTOMATED WORKCELLS. THE INTELLIGENT COMMUNICATION INTERFACES (ICI) LINK THE LOWER LEVEL REAL-TIME SENSOR AND HARDWARE CONTROL PROCESSES TO THE UPPER LEVEL KNOWLEDGE-BASED PLANNING AND SUPERVISORY PROCESSES. THE COMPUTING STRUCTURE IS PARTITIONED TO ISOLATE THE COMPUTATIONALLY SLOW PLANNING FUNCTIONS FROM THE REAL-TIME CONTROL FUNCTIONS.

INTEGRATED FLEXIBLE WELDING SYSTEM

System Architecture (Continued)

The weld planner subsystem is an expert system which constructs a welding strategy from the workpiece design and an associated body of welding knowledge. This body of knowledge exists as a set of welding rules which were developed from information collected during consultation with several welding experts. The strategy includes an ordered set of weld sequence information as well as initial settings of associated process control parameters. The weld process and geometric information generated by the weld planner are output to the execution coordinator and path planner, respectively. Tests of the weld planner structure have been successful and expansion of the set of possible configurations is currently underway.

The path planner examines the weld strategy information to determine which of the options the workcell robot can execute without collisions. The path planner obtains the position and orientation of the workpiece in the workcell envelope from the global vision sensor. If possible, a complete movement plan is constructed and sent to the execution coordinator. This plan is determined by examining the workcell from the gross and fine motion planning perspectives. During gross motion planning, the path planner proposes basic movements, simulates those movements using a geometric modeler, then checks the path for interference with the various parts of the workcell. The fine motion planning phase utilizes similar "generate and test" procedures to plan the fine movements of the robot, in order to place the seam tracking sensor of the workcell within the range and view of the seam.

The execution coordinator assembles the weld process information and movement plan into a complete plan. This complete plan is then divided into component strategies for each subsystem. The execution coordinator also constructs a set of sensor state expectations to monitor the plan's implementation. If all goes well, the execution coordinator does nothing active after welding has begun. If deviations from expectations occur, however, the coordinator tries to correct the situation through minute plan changes. Past a certain point of deviation, this component stabilizes the process as best it can and calls other subsystems for help. The execution coordinator consists of a domain-independent inference engine coupled to limited subsets of the weld planner and path planner databases. It is capable of simultaneous plan sequencing and sensor feedback analysis and is designed to directly interface with Intelligent Communication Interfaces in the IFWS.

INTEGRATED FLEXIBLE WELDING SYSTEM ARCHITECTURE

- UPPER LEVEL ARCHITECTURE:
  - DESIGN INTERFACE
    - -- COMPUTER-AIDED-DESIGN (CAD) WORKSTATION
    - -- USER ACCESS TO ENTIRE IFWS OPERATION
    - -- MAJOR INPUT/OUTPUT DEVICE
  - WELD PLANNER
    - -- CONSTRUCTS WELDING STRATEGY FROM WELDMENT DESIGN AND A BODY OF WELDING KNOWLEDGE
    - -- BASED ON RULES FORMULATED BY WELDING EXPERTS
  - PATH PLANNER
    - -- EXAMINES WELD STRATEGY
    - -- DETERMINES OPTIONS FOR EXECUTION
    - -- MANAGES COLLISION AVOIDANCE
  - EXECUTION COORDINATOR
    - -- GENERATES COMPLETE PLAN FROM WELD PROCESS INFORMATION AND MOVEMENT PLAN
    - -- SEPARATES COMPONENT STRATEGIES FROM THE OVERALL WELD PROCESS PLAN
    - -- MONITORS THE WELD PROCESS FOR CONFORMITY TO THE WELD PLAN
    - -- PERFORMS SENSOR FEEDBACK ANALYSIS AS IT ISSUES PLAN SEQUENCES
  - LINKED TO LOWER LEVEL BY INTELLIGENT COMMUNICATIONS INTERFACES (ICI)
- LOWER LEVEL ARCHITECTURE:
  - INTERACTS WITH WORKCELL ENVIRONMENT
  - SPECIFIC SENSOR, CONTROL AND HARDWARE SUBSYSTEMS
    - -- ROBOTIC ADAPTIVE WELDING SYSTEM
    - -- GLOBAL VISION SYSTEM
    - -- 3-D WELD SEAM TRACKING SYSTEM
    - -- WELD PROCESS SENSORS

INTEGRATED FLEXIBLE WELDING SYSTEM

Vision Subsystem Overview

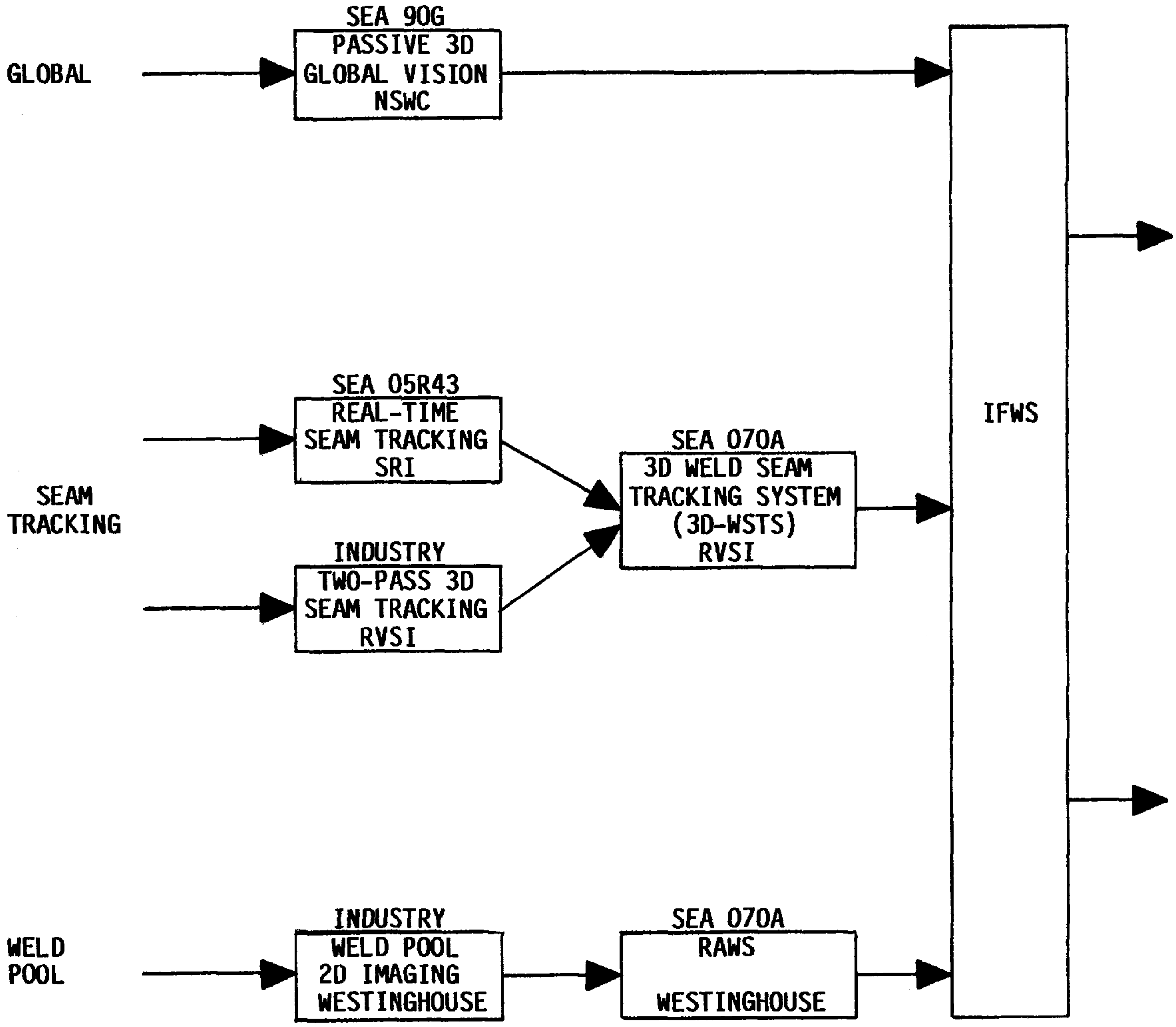
To achieve the required system intelligence for low-volume operations in unstructured environments, the conceptual design of the IFWS includes three separate vision subsystems:

- The first, the Global Vision System (GVS), will provide an overview of the entire workcell, collecting 3-D data for workpiece identification and orientation, as well as collision avoidance between the workpiece and robot end-effector.

- The second system, the 3-D Weld Seam Tracking System (3-D WSTS), will scan a few inches ahead of the welding torch to provide advance 3-D information on the geometry of the workpiece and volumetric information about the weld joint gap.

- The third vision system, the Weld Pool Imaging System, employs a 2-D capability for close-in viewing of the weld pool to provide detailed information on its dimensions and shape for process control, as well as its position with respect to the seam. A discussion of the weld pool vision system is contained in the article on the Robotic Adaptive Welding System (RAWS).

VISION SYSTEMS



INTEGRATED FLEXIBLE WELDING SYSTEM

Global Vision System

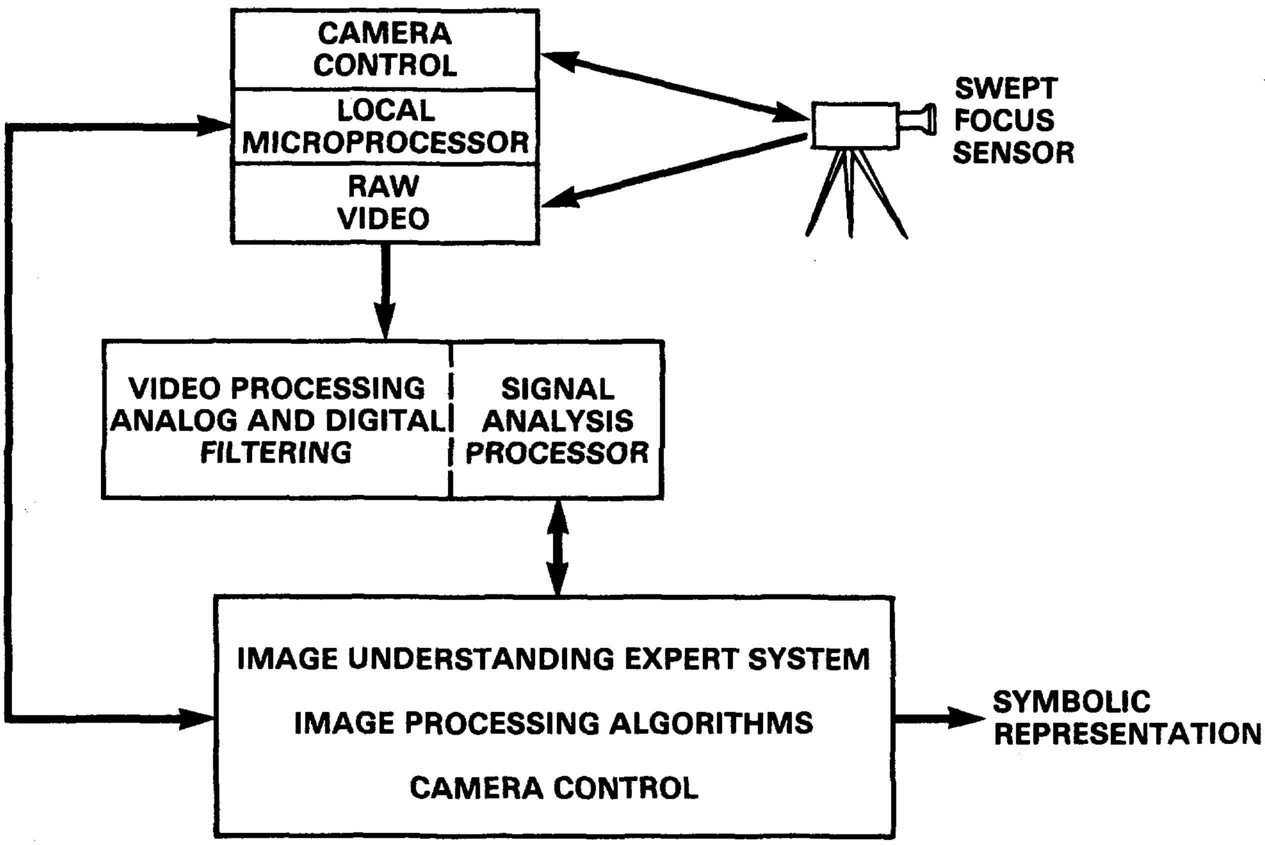
The Global Vision System (GVS) was proposed in response to the IFWS need to accurately locate the parts to be welded in the workcell, and will provide the Path Planner and Weld Planner expert systems the necessary information regarding workcell geometry and part location. The objective of the GVS program is to develop a computer-based vision system employing special optical preprocessing and image understanding techniques to achieve three-dimensional, near-real-time machine vision. The system must be able to recognize and locate parts to be welded in the IFWS workcell to an accuracy of one-half inch to assist in initial positioning of the welding torch and provide for collision avoidance. This IFWS component is being developed by the Robotics Program Office of the Naval Surface Weapons Center (NSWC), White Oak, MD.

The first GVS subcomponent is the 3-D Vision Camera Subsystem, being developed by Associates and Ferren, Wainscott, NY. This innovative approach to 3-D imaging uses a servo-driven, very shallow depth-of-field scanning-lens camera system to quickly determine distance to various target features. The narrow focus feature creates a series of 2-D image slices as the lens system scans. This enables "2-1/2 D" reconstruction of a representation of the viewable portion of the 3-D object. Any items in the foreground or background that are not of interest are not processed.

The second subcomponent is the Image Understanding Expert System (IUES) being developed by John Moscar of NSWC. The objective of the IUES is to control the 3-D camera system and evaluate the resulting images. The expert system, manipulating a computer-aided-design (CAD) model of the part, will reconstruct the entire 3-D image using rotation and template matching. By manipulating any "a priori" information and knowledge about expected conditions in the IFWS workcell, the system determines the part identity and location in accordance with the IFWS requirements. The IUES is being created on the Symbolics 3670 LISP machine using the OPS5e Expert System development program, existing Fortran 77 image analysis routines, and other "low-level" analysis software.

The GVS will be given the part ID and will have access to the IFWS CAD database of part solid models, and will know the "world coordinates" of the workcell and its geometry. All processing will be done off-line when no actual welding is occurring. The Global Vision System will output the information in a symbolic format instead of large raw data transfers, communicating over the Ethernet bus via an Intelligent Communications Interface (ICI).

GLOBAL VISION SYSTEM



THE COMPUTER-BASED GLOBAL VISION SYSTEM (GVS) UNDER DEVELOPMENT BY NSWC WILL BE CAPABLE OF RECOGNIZING AND LOCATING PARTS TO BE WELDED WITHIN THE IFWS WORKCELL, FOR THE PURPOSES OF ROBOT POSITIONING AND COLLISION AVOIDANCE. THE GVS, CONSISTING PRIMARILY OF THE 3-D VISION CAMERA SUBSYSTEM AND THE IMAGE UNDERSTANDING EXPERT SYSTEM, WILL EMPLOY SPECIAL OPTICAL PREPROCESSING AND IMAGE UNDERSTANDING TECHNIQUES TO ACHIEVE THREE-DIMENSIONAL, NEAR-REAL-TIME MACHINE VISION.

INTEGRATED FLEXIBLE WELDING SYSTEM

3-D Weld Seam Tracking System

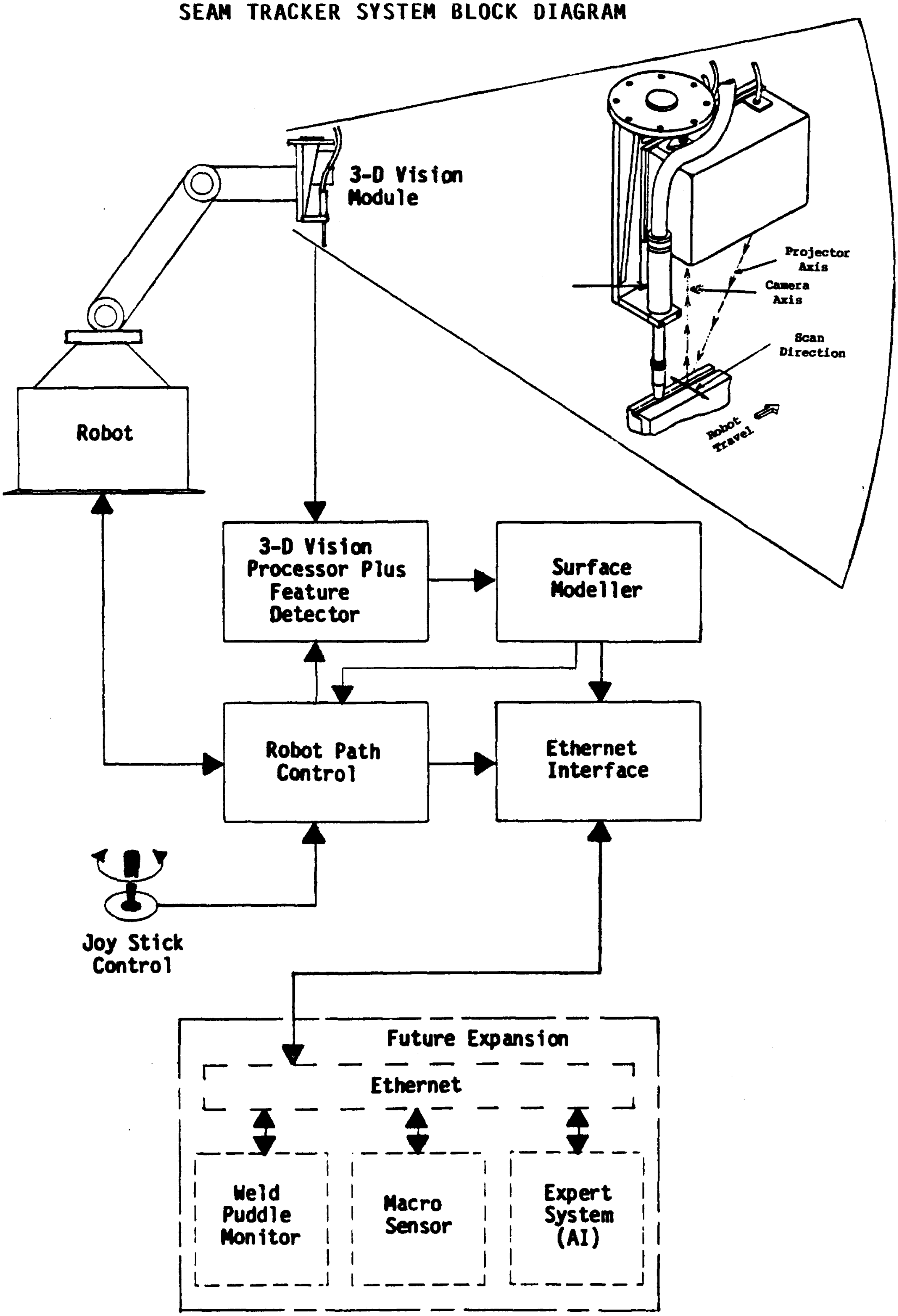
Another major component of the IFWS is the three-dimensional weld seam tracking system (3-D WSTS). Its purpose is to provide single-pass, real-time guidance of the welding torch. The system scans a few inches ahead of the arc to provide three-dimensional information on the geometry of the workpiece and volumetric information about the weld gap.

A contract was awarded to SRI International in 1981 to develop a single pass, 3-D weld seam tracking system for use in a shipyard environment. An existing prototype sensor designed by SRI was to be upgraded for this effort. This sensor operated by projecting a coded pattern of light onto the workpiece and interpreting distortions of the image caused by intersection with the workpiece surface, as viewed by a two-dimensional camera a fixed distance away. Disadvantages of this approach included the long noise integration time associated with the two-dimensional detector operating in the presence of the weld arc, and the inability to deal with specular reflections caused by some workpiece surfaces. An improved second-generation sensor subsequently developed by SRI under contract with the Navy employed optical triangulation, and projected a collimated beam of light emitted by a laser diode onto the workpiece surface. The laser spot was mechanically scanned back and forth by a mirror to create a line of intersection with the workpiece, and was detected by a 256 element linear array. The result was a markedly improved signal-to-noise ratio, relatively free of optical and electrical noise created by the weld arc. The laboratory prototype built by SRI was successfully demonstrated welding on both aluminum and steel.

A contract, to improve the sensor for use in a production environment (IFWS), and to develop a very fast pipeline architecture to process the data, was awarded in September 1984 to Robotic Vision Systems, Inc. (RVSI), with SRI International as a subcontractor.

The 3-D WSTS consists of a seam tracking sensor with its associated controller hardware and software, a Cincinnati Milacron T3-776 electric robot equipped with a weld torch, and an operator interface with off-line programming capabilities. The tracker controller is a 68010-based machine which utilizes the Versabus bus structure. The front-end image processing software results in real time seam parameter recognition and true 3-D seam coordinates. The surface modeler produces a simulation of the weld sequence on a console for monitoring of the weld process.

SEAM TRACKER SYSTEM BLOCK DIAGRAM



INTEGRATED FLEXIBLE WELDING SYSTEM

3-D Weld Seam Tracking System (Continued)

Operator interaction with the system takes place through a menu driven console activated by a keyboard or a mouse. Through this interface, the operator can select and monitor weld parameters, teach the robot new weld sequences, and position the end-effector. Robot motion can also be controlled by a six degree-of-freedom joystick, reducing teaching time by almost 50 percent. Provided with the operator interface is an off-line programming capability known as SKETCH. SKETCH guides the operator through the teaching of weld sequences and automatically produces and stores the programs required to perform the welds.

The NAVSEA sponsor responsible for directing the 3-D WSTS effort is Roy Wells (SEA 070A). All individual hardware and software components of the 3-D WSTS have been completed, and component testing, systems integration, and calibration are underway. An end-of-project demonstration for the seam tracking system is scheduled for May 1986.

3-D WELD SEAM TRACKING SYSTEM

- PURPOSE: TO PROVIDE SINGLE-PASS, REAL-TIME GUIDANCE TO THE WELDING TORCH

- COMPONENTS:

  - TRACKING SENSOR
  - CINCINNATI MILACRON T3-776 INDUSTRIAL ROBOT
  - GAS METAL ARC WELDING TORCH
  - CONTROL HARDWARE
    - 68010-BASED PIPELINE ARCHITECTURE
    - VERSABUS
  - CONTROL SOFTWARE
    - 3-D VISION PROCESSOR
    - SURFACE MODELER
    - OFF-LINE PROGRAMMING - "SKETCH"
  - USER INTERFACE
    - CONSOLE WITH KEYBOARD
    - MOUSE
    - SIX DEGREE-OF-FREEDOM JOYSTICK

- STATUS:

  - INDIVIDUAL HARDWARE AND SOFTWARE COMPONENTS COMPLETE
  - CURRENTLY WORKING ON SYSTEMS INTEGRATION
  - END OF PROJECT DEMO - MAY 1986

INTEGRATED FLEXIBLE WELDING SYSTEM

Robotic Adaptive Welding System

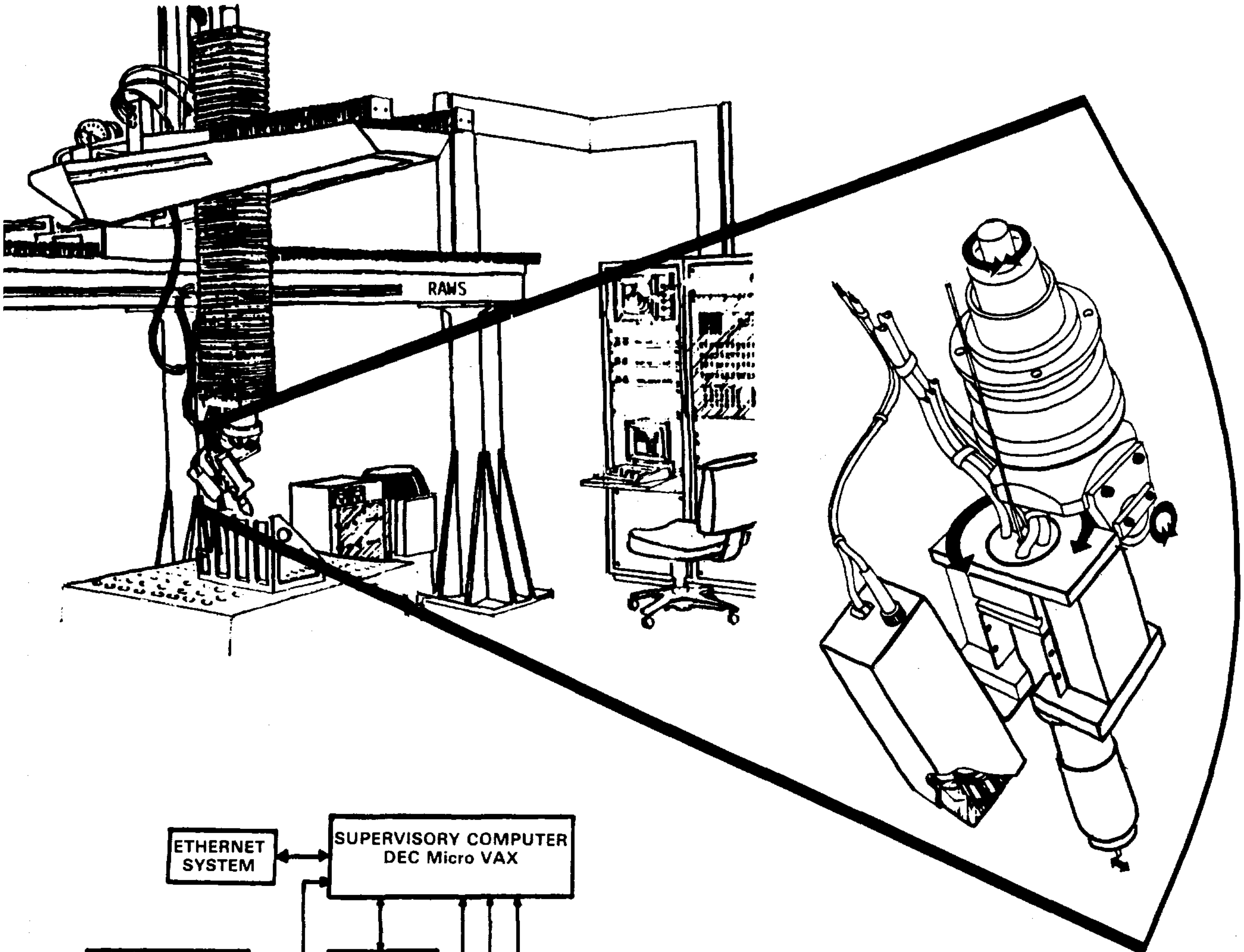
One of the primary supporting modules of the IFWS is the Robotic Adaptive Welding System (RAWS), a project managed by NAVSEA 070A under the Navy Manufacturing Technology Program. RAWS is being developed at the Westinghouse Research and Development Center and is specifically aimed at the problems of small batch manufacturing. The initial RAWS system is built around an advanced GMAW welding torch mounted on a Unimate 6000 robot, equipped with a Westinghouse weld pool vision sensor.

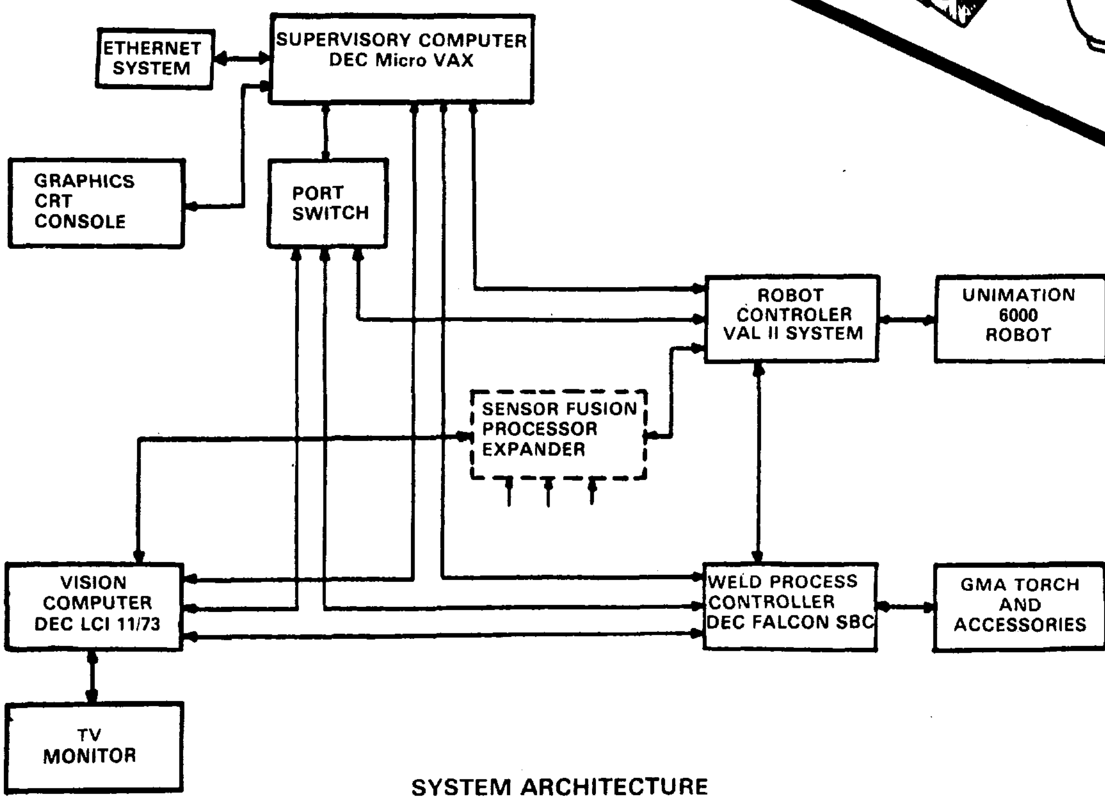
RAWS is intended to provide adaptive control of an enhanced GMAW welding capability, optimized for robotic implementation. The system's ability to maintain desired weld quality under varying conditions is achieved through use of a weld pool imaging system and associated adaptive control algorithms.

The weld process control feedback allows for consistent quality production welds when subassembly preparation and fit-up cannot be optimized, typically the case in a shipyard environment. The characteristic unstructured conditions and low-volume lot sizes present several challenges which fostered the innovative developments embodied in the RAWS project. The advanced gas metal arc welding process, under development by Westinghouse, utilizes an in-line electrical preheat of filler wire, which helps to reduce the interdependence of arc voltage, current, stickout, and wire feed parameters during welding. The weld pool imaging system provides feedback of actual weldment characteristics, permitting adaptive control of process parameters in a real-time manner, without operator intervention.

Operational testing of the laboratory prototype has demonstrated satisfactory performance on a number of materials and joint configurations, including groove, butt, lap and T-fillets. The capability of the sensor to direct adaptive control has been addressed during two experiments conducted by the contractor. RAWS will be ready for demonstration as an interim stand-alone capability in the third quarter FY 86.

ROBOTIC ADAPTIVE WELDING SYSTEM





SYSTEM ARCHITECTURE

LASER ARTICULATED ROBOTIC SYSTEM

A laser-based metal working process, due to its very nature, must be implemented on an automated system. There are no comparable manually-performed operations such as is the case with gas metal arc welding. The laser process is also unique in that a single system can be used to cut, weld, and mark parts used in component fabrication, offering considerable potential for cost savings in equipment and material handling needs.

Application of high-power lasers for use in materials processing has been limited because in most operational systems to date, the workpiece must be moved while the laser beam remains fixed. The set-up process is time consuming because of the fixturing and alignment requirements necessary to ensure that the weld joint and the small diameter focused beam are coincident. Pennsylvania State University has a program underway to develop for SEA 06L1 a Laser Articulated Robotic System (LARS), which will expand the application of laser technology by addressing these issues. LARS will provide for precision manipulation of a laser beam for metal fabrication and processing through the application of real-time adaptive systems.

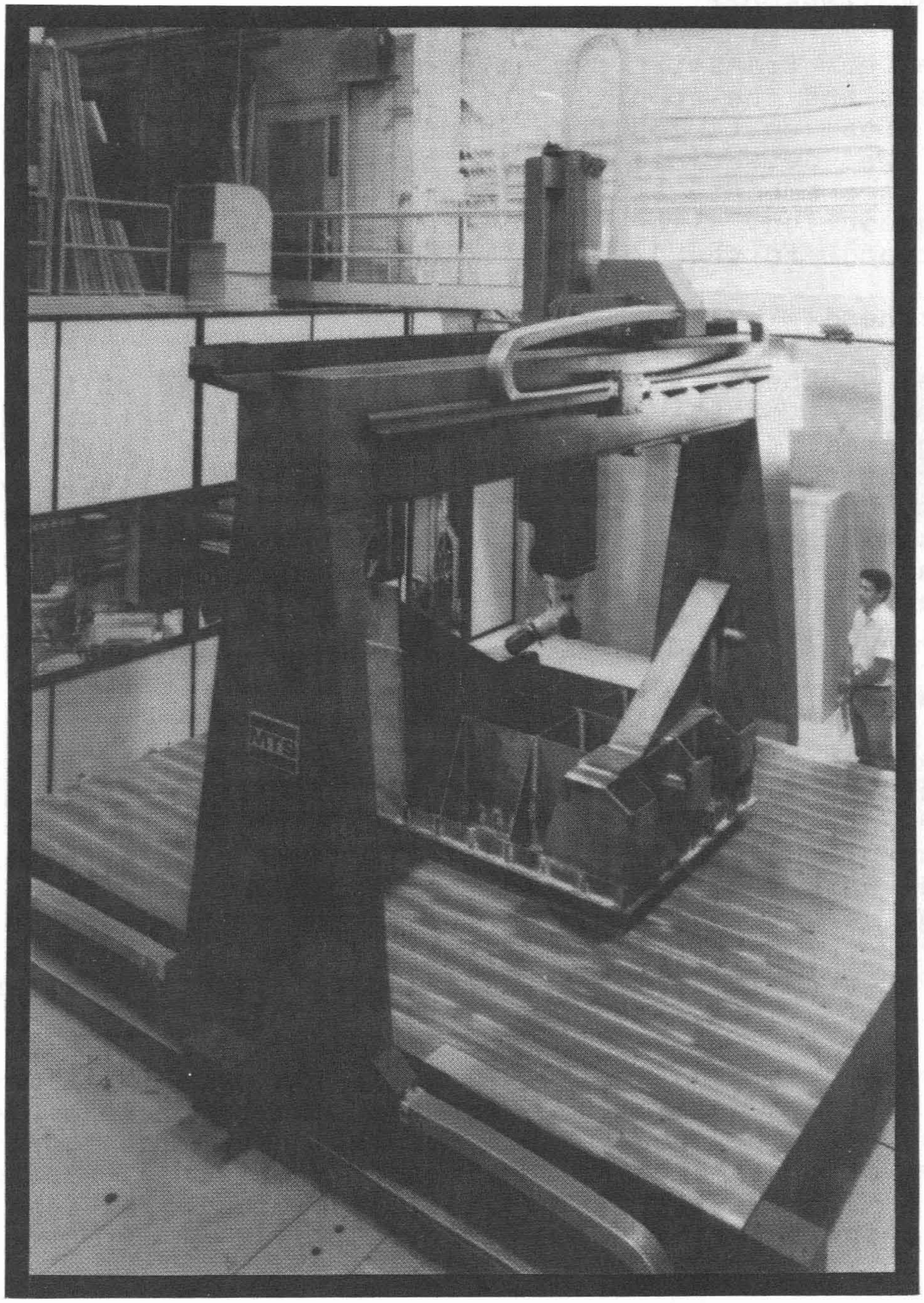
The first thrust for the LARS program has been the development of sensors for seam tracking and space location, to be evaluated on the prototype shown on the facing page. After sensor development and evaluation are completed, this testbed will be converted to a LARS Process Development Machine (PDM), with the capability to manipulate a laser beam. The system will be interfaced with a 15 kw laser at the Westinghouse Research and Development Center for system evaluation, demonstration, and technology transfer. After intensive evaluation, an improved system will be developed for factory application.

LARS is a complex configuration consisting of six major subsystems: the robot, beam transport, workhead, vision, electronic control, and software. Some of these subsystems are described below.

Robot

A gantry-based robot has been selected as the only configuration providing the necessary reach to accommodate the required working envelope. The gantry provides X, Y, and Z translation of the beam, and an articulated arm provides the remaining degrees of freedom required for welding and cutting. The robot, being designed for the project by MTS Systems Corporation, is sized to permit welding of items as large as 11 feet x 11 feet x 2 feet in the down-hand welding position and 4 feet x 4 feet x 4.5 feet in the horizontal position.

LASER ARTICULATED ROBOTIC SYSTEM



DEVELOPED FOR NAVSEA BY MTS SYSTEMS, LARS PROVIDES FOR PRECISION MANIPULATION OF A LASER BEAM FOR METAL FABRICATION AND PROCESSING THROUGH THE APPLICATION OF REAL-TIME ADAPTIVE SYSTEMS.

LASER ARTICULATED ROBOTIC SYSTEM (Continued)

Beam Transport

The beam transport system provides the interface between the laser and the robot. This system must internally transport the beam up to 150 feet in an oil and dirt free environment. It was determined that the beam transport system would have to accommodate a 6-inch beam to reduce divergence-induced degradation. The beam diameter will be reduced at the entrance to the "Z axis" column.

Workhead

The workhead is attached to the lower end of the "Z axis" component of the gantry, and provides the articulated motion required for complex metalworking. The workhead is an integrated system of mechanical and electromechanical components which focuses the laser beam, and provides final positioning of both the beam and process-related hardware near the workpiece. The workhead includes a gas shield for plasma suppression, a wire feeder, a seam tracker, and a cutting jet.

Vision

The positioning requirements for LARS include tracking the center of a butt joint to within 0.005 inches, maintaining the desired standoff distance to within 0.015 inches, and controlling the angle of the incident beam with respect to the workpiece to 90 degrees, $\pm$ 1 degree. This tracking requirement must be met for random path welds in a work envelope measuring 20 feet x 20 feet x 10 feet without preprogramming, while operating at speeds of 200 inches per minute.

MTS Systems in Minneapolis, MN, is the principal development contractor, with Westinghouse Advanced Energy Systems Division as the subcontractor responsible for the beam transport system. Delivery of the Process Development Machine is scheduled for September 1987, with demonstrations beginning as soon as the system is operational.

LASER ARTICULATED ROBOTIC SYSTEM
PRIMARY SPECIFICATIONS

- WORKPIECE ENVELOPE
  - DOWNHAND 11 FT. X 11 FT. X 2 FT. HIGH
  - HORIZONTAL 4 FT. X 4 FT. X 4.5 FT. HIGH
- MACHINE ENVELOPE
  - EXCLUDING GENERATOR AND CONTROLS
  - 17.5 FT. X 15.5 FT. X 18.2 FT. HIGH
- LASER GENERATOR CAPACITY - UP TO 25KW
- OPERATIONAL VELOCITIES - UP TO 200 INCHES/MINUTE
- PRIMARY OPERATIONAL MODES
  - WELDING - AUTOMATIC RANDOM SEAM TRACKING
  - CUTTING - PRE-PROGRAMMED PATH FOLLOWING
- ACCURACIES
  - $\pm$ 0.005 INCH WITHIN DESIRED PATH
  - $\pm$ 3% VELOCITY ACCURACY
  - $\pm$ 0.030 INCH FOCAL DISTANCE ACCURACY
  - $\pm$ 1 DEGREE ORIENTATION ANGLE ACCURACY
- BEAM FOCUS OPTICS
  - F/7 REFLECTIVE OPTICS
  - 0.040 INCH FOCUS SPOT DIAMETER

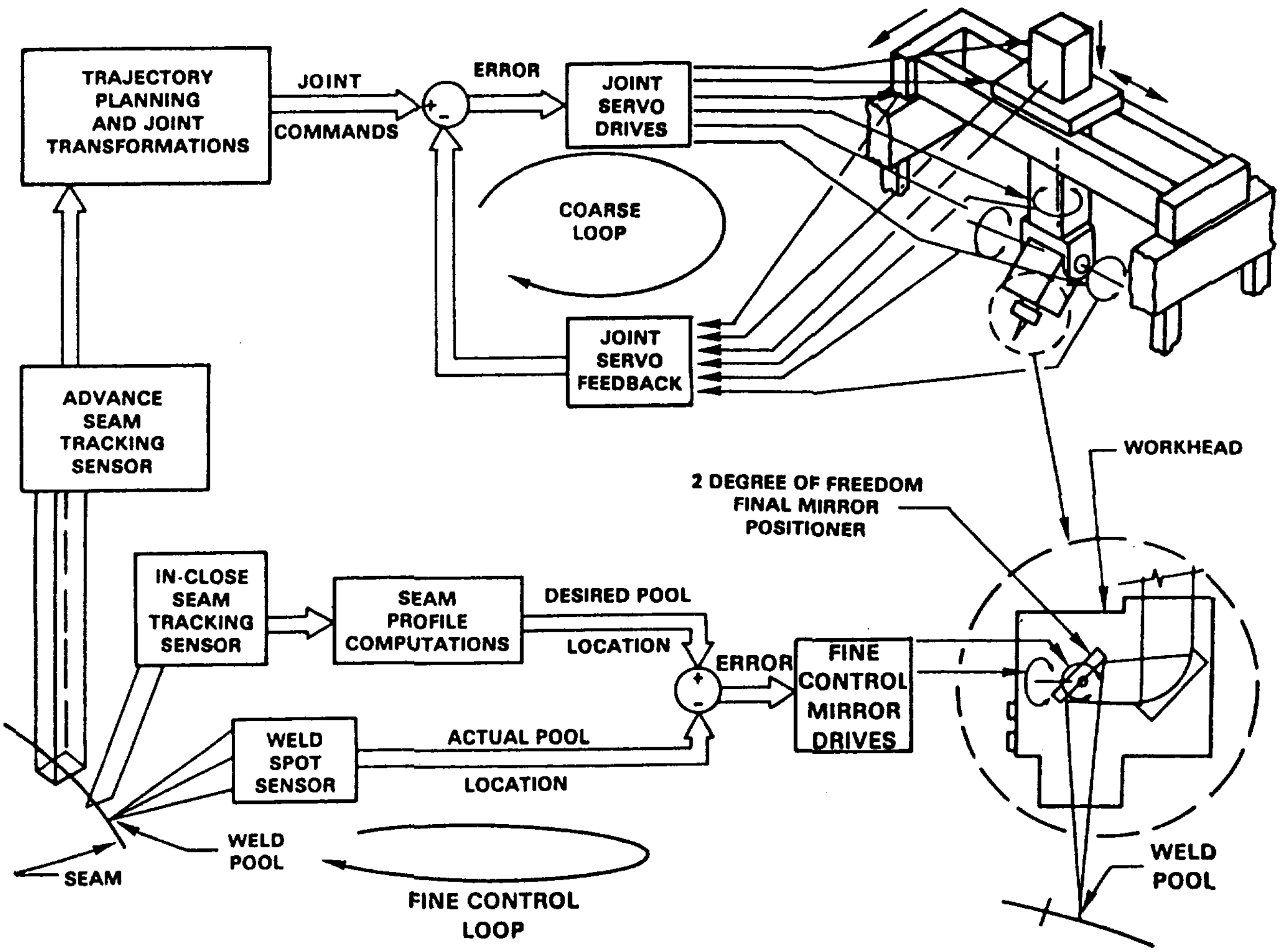
LASER ARTICULATED ROBOTIC SYSTEM (Continued)

Tracking System

The weld seam guidance problems associated with laser welding differ significantly from those associated with arc welding. For autogenous butt welds, the small weld spot diameter (0.040 in.) requires tracking accuracies to within 0.005 in. to ensure that the beam hits both pieces being welded. Beam drift is caused by inaccuracies in the robot, mirror misalignment, and mirror heating, as well as temperature and atmospheric pressure variations. In addition, the part moves due to thermally induced stresses during the weld operation. For these reasons, two guidance systems are employed to close the control loop between the workhead and workpiece. One guidance system scans just slightly ahead of the weld pool and detects the location of the seam, providing path correction data to the robot controller directing the motions of the end-effector. The other system focuses directly on the weld spot, determines its position relative to the center of the weld seam, and sends this information to the final mirror controller for continuous positioning adjustment through dynamic alignment of the mirror itself. These two systems must work together in real-time through an intelligent control interface to keep the weld spot accurately positioned. The seam position data is collected at a rate of one kilohertz and the final position adjustment is made at 200 hertz.

The initial LARS demonstration system, planned for FY 86, will consist of a half-scale system with limited high level intelligence, intended for vision system testing and concept evaluation. The subsequent system will be a full-scale demonstration, including knowledge-based control strategies, for a truly adaptive laser welding capability.

LARS TRACKING SYSTEM



- WELD SEAM GUIDANCE PROBLEMS FOR LASER WELDING:
  - TRACKING ACCURACIES REQUIRED TO WITHIN 0.005 IN.
  - BEAM DRIFT AND THERMALLY INDUCED STRESSES
- TWO GUIDANCE SYSTEMS REQUIRED TO FUNCTION TOGETHER IN REAL TIME:
  - DETECTION OF WELD SEAM LOCATION AND PATH CORRECTION DATA
  - DETERMINATION OF WELD SPOT POSITION RELATIVE TO CENTER OF WELD SEAM

LASER WELDED CATAPULT LAUNCH RAIL ASSEMBLIES

In FY 85 the Navy funded, under subcontract to ARL, a project entitled "Program to Demonstrate Applications of Wear Resistant Coatings on Naval Aircraft Launch Rails Using a High Power Laser". The development work was done at the Westinghouse Electric Research and Development Center. The purpose of the project was to investigate the possibility of using a laser to produce load bearing and sealing welds between catapult trough covers and tracks to produce one piece assemblies. The laser was to make 1.25 inch deep welds at the top and bottom interfaces of the trough cover with the catapult track, while maintaining dimensional and mechanical requirements of the assembly. This process would replace the bolts and eventually the load bearing keyway now being used to attach the tracks to the trough covers.

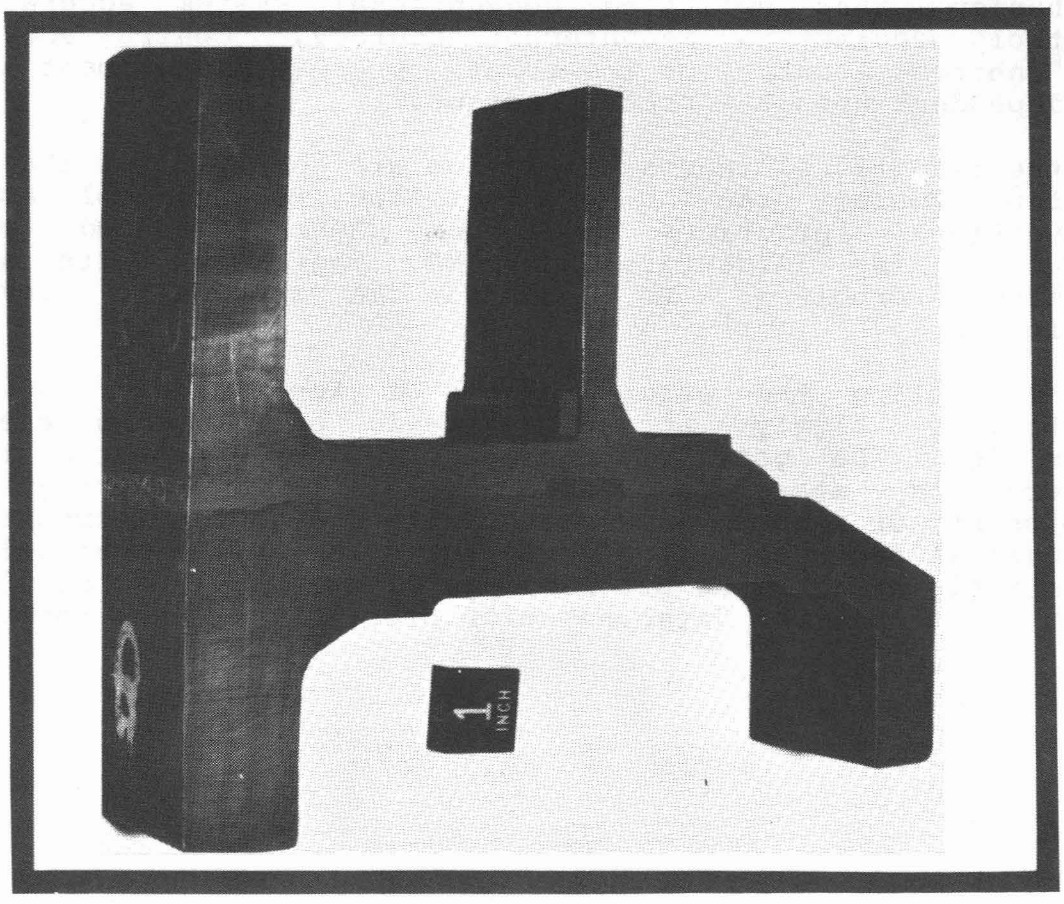
The laser welding process was developed at the Westinghouse R&D Center to produce deep, narrow-groove welds with hot wire filler material, using the laser as a welding heat source. The process was successfully demonstrated making preliminary welds in 1.5 inch thick plates of HTS and 4140 steels used in the trough covers and tracks, respectively. Similarly successful welds were made in foot-long assembly sections.

Specimens were taken from the welds and tested for strength and toughness, and were found to meet the requirements set by the Navy. In addition, fatigue, fatigue crack growth rate, and KISCC tests were begun, and are nearing completion. Distortion measurements on the laser weld revealed that distortion was equivalent to that found in conventional welds of one-third the depth.

Five full-size trough cover/track assemblies were welded, and the process was successfully demonstrated to Navy officials. Procedures were documented and submitted to NAEC for use in the generation of a production requirement document. In addition, a full size trough cover assembly was shipped to NAEC for fatigue testing.

Further testing is underway, and process procedures are being refined to minimize thermally induced distortion in the assembly. Future work includes laser cladding of wear areas, and a determination of resulting physical properties. The final goal is to demonstrate an ability to produce acceptable one-piece trough cover/track assemblies, and perform rework type repairs on such assemblies using a high power laser.

AIRCRAFT CARRIER CATAPULT TROUGH COVER



TRANSVERSE CROSS SECTION OF LASER WELDED CATAPULT TROUGH COVER

INTELLIGENT ROBOTIC INSPECTION SYSTEM

A SEA 06L1 Manufacturing Technology project, managed by Henry Watson of Penn State, was initiated in 1985 to develop new inspection technology to meet the immediate and future inspection needs of the Navy. As higher accuracies are required in part manufacture, the process of ensuring components and complex assemblies meet specifications increases significantly because of lack of high-speed precision inspection equipment. Present methods of inspection include the use of gauge blocks, precision indicators, and bore gauges, in combination with granite or scraped-steel surface plates. There are many problems associated with the application of these devices, and in many cases the accuracy of the measurements is operator dependent.

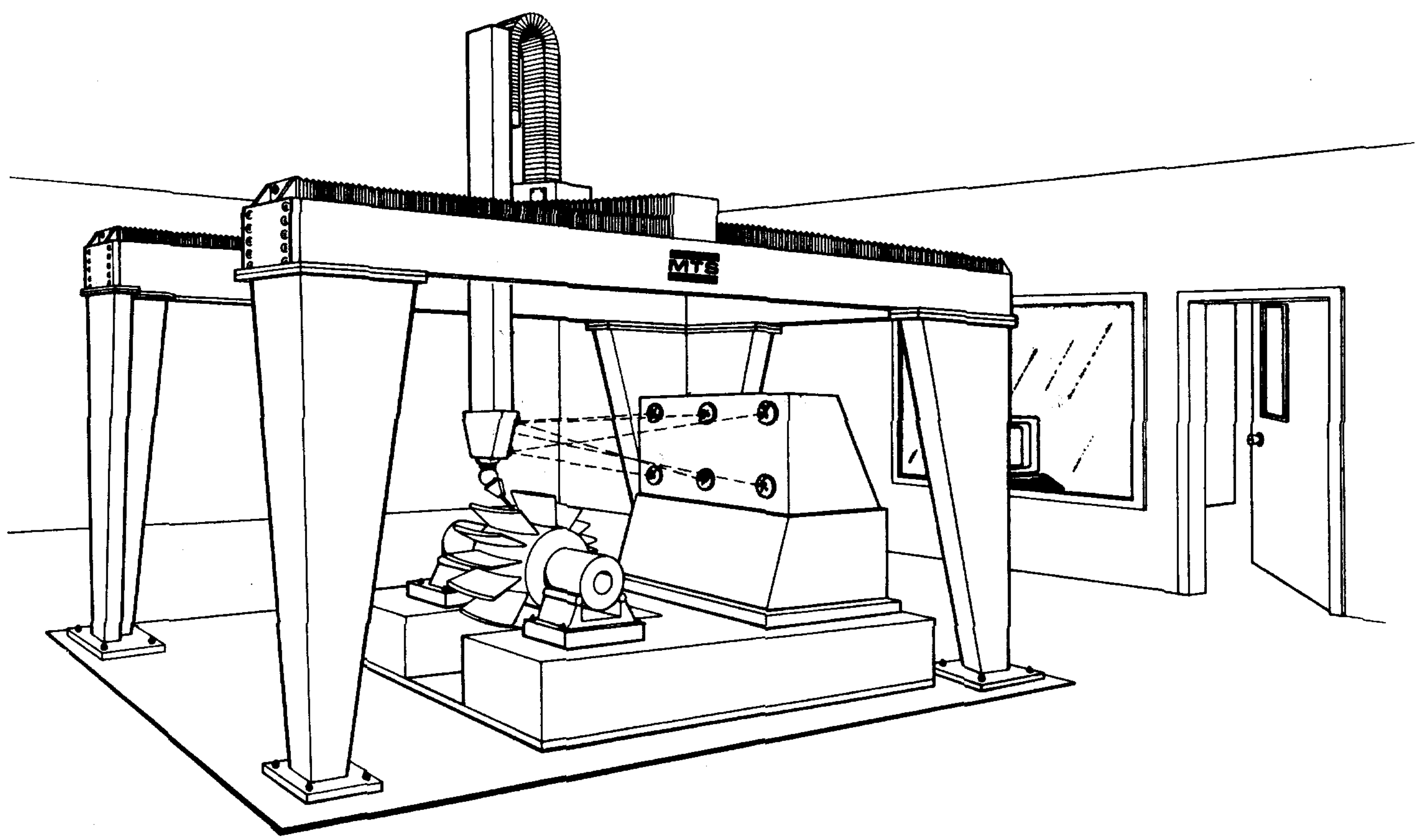
This effort to execute a highly accurate inspection workcell is known as the Intelligent Robotic Inspection System (IRIS) (previously referred to as the Non-Contact Precision Parts Profiler). The technologies incorporated into IRIS include: (1) unstressed world coordinate and orientation measurement, (2) non-contact workpiece sensing, (3) advanced robotic control, and (4) advanced user interface capabilities.

In the design of IRIS, it was decided to functionally separate the measurement sensing mechanism from the robot transport mechanism, thus splitting conventional system accuracy into control accuracy and measurement accuracy. Control accuracy is the inherent accuracy of the robot, whereas measurement accuracy is dependent upon the sensor systems.

In the traditional approach, the two are coupled, and the overall system accuracy can be no better than the control accuracy. Conventional practices rely upon sheer mass and physical structure (as illustrated in APOMS, page 50), with all the inherent problems, to maintain an acceptable level of performance.

By decoupling the error sources of the robotic positioning mechanism, highly accurate dynamic measurements are made possible. The goal of the program is to develop a robotic, laser-based measuring system capable of comparing actual component or assembly dimensions with design requirements, with an overall accuracy of 0.0005 inches. The system controller will be capable of off-line programming, either by direct digital data input or from a CAD database which precisely defines the part.

INTELLIGENT ROBOTIC INSPECTION SYSTEM



- MANUFACTURING TECHNOLOGY PROJECT INITIATED IN EARLY 1985 FOR DEVELOPMENT OF INSPECTION TECHNOLOGY
- GOAL:
  - HIGHLY ACCURATE INSPECTION WORKCELL
  - NONCONTACT LASER BASED MEASUREMENT SYSTEM
  - COMPARE COMPONENT DIMENSIONS WITH DESIGN REQUIREMENT
  - OVERALL ACCURACY OF 0.0005 INCHES
  - CAPABLE OF OFF-LINE PROGRAMMING
- CURRENTLY IN FINAL DESIGN STAGE
- SCHEDULED FOR COMPLETION IN SEPTEMBER 1986

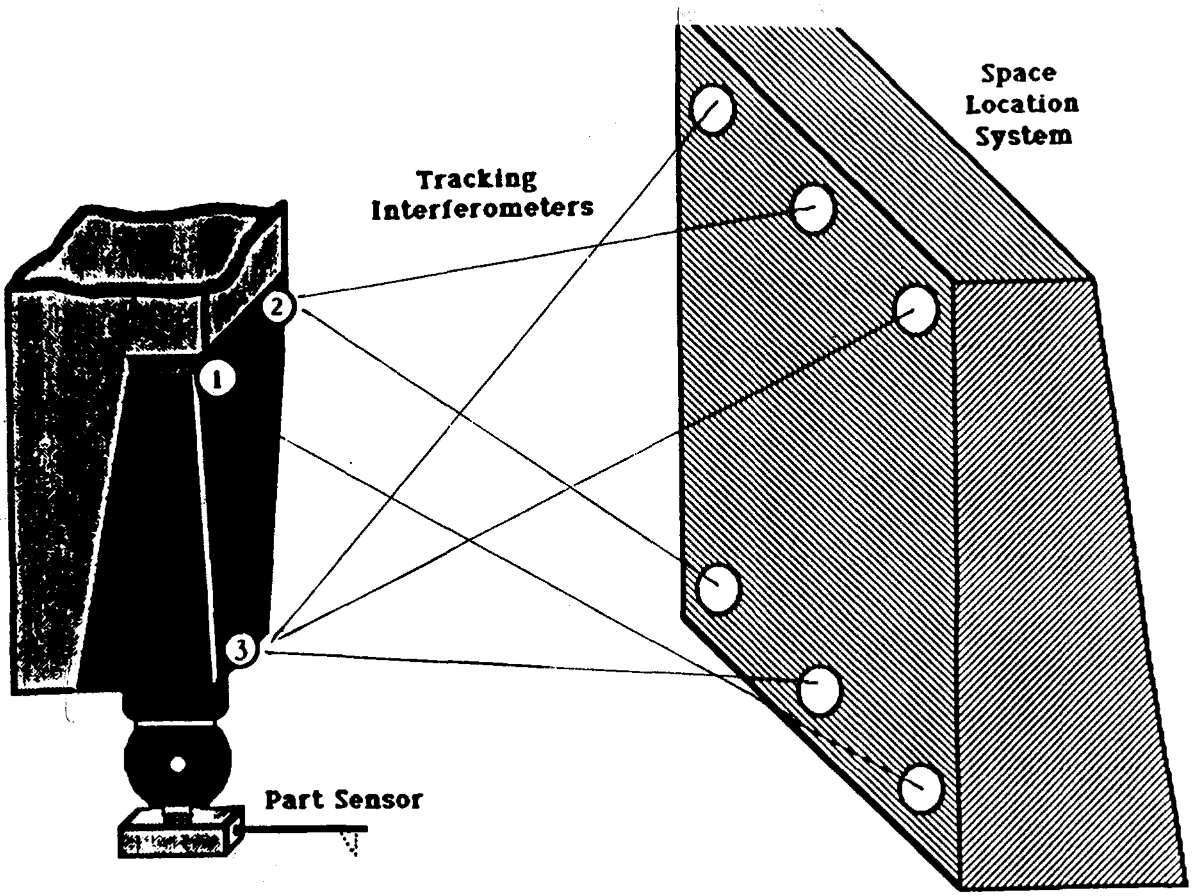
INTELLIGENT ROBOTIC INSPECTION SYSTEM (Continued)

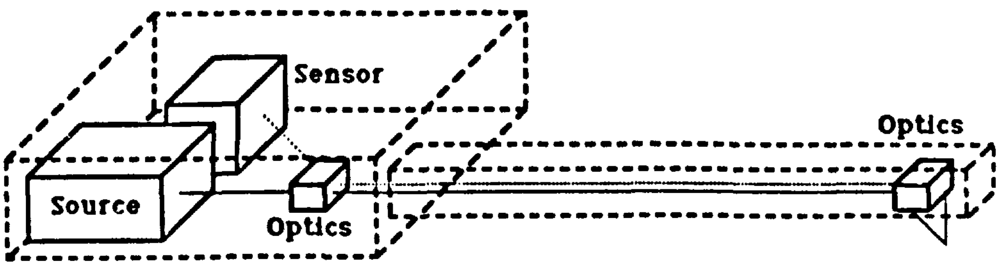
During operation, the robot is guided by a space location system consisting of 6 laser interferometers and 3 retro-reflectors, capable of measuring absolute distance from a reference point with an accuracy of approximately 10 microinches. The 6 distance measurements to the end-effector define its position in world coordinates to an accuracy of .00025 inches in a working envelope measuring 3 ft. x 3 ft. x 3 ft. The effective envelope is extended through the use of a precision turntable.

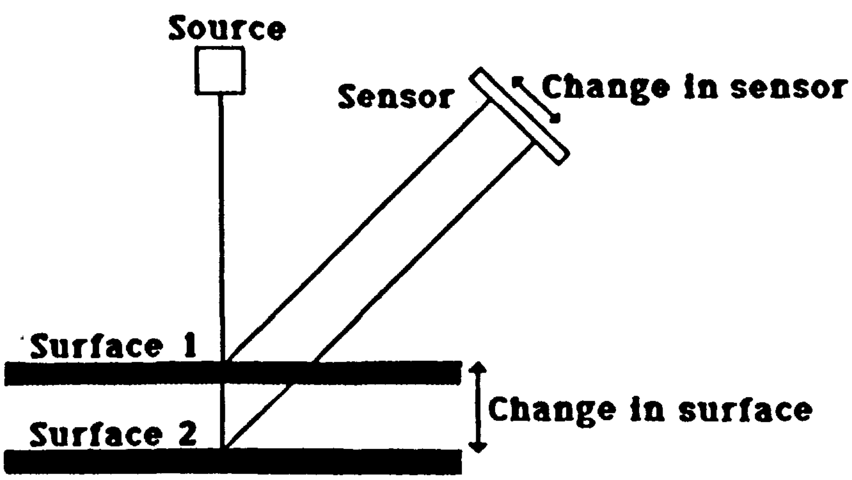
The part measurement sensor uses conventional laser triangulation with a CCD linear array to provide non-contact measurement of the workpiece to an accuracy of .00025. (The system thus has an overall dynamic accuracy of ± 0.0005. in.)

IRIS is currently in the final design stage and is scheduled for completion in September 1986. After installation, an extensive program of technology transfer will be implemented to allow this concept to benefit other applications.

INTELLIGENT ROBOTIC INSPECTION SYSTEM







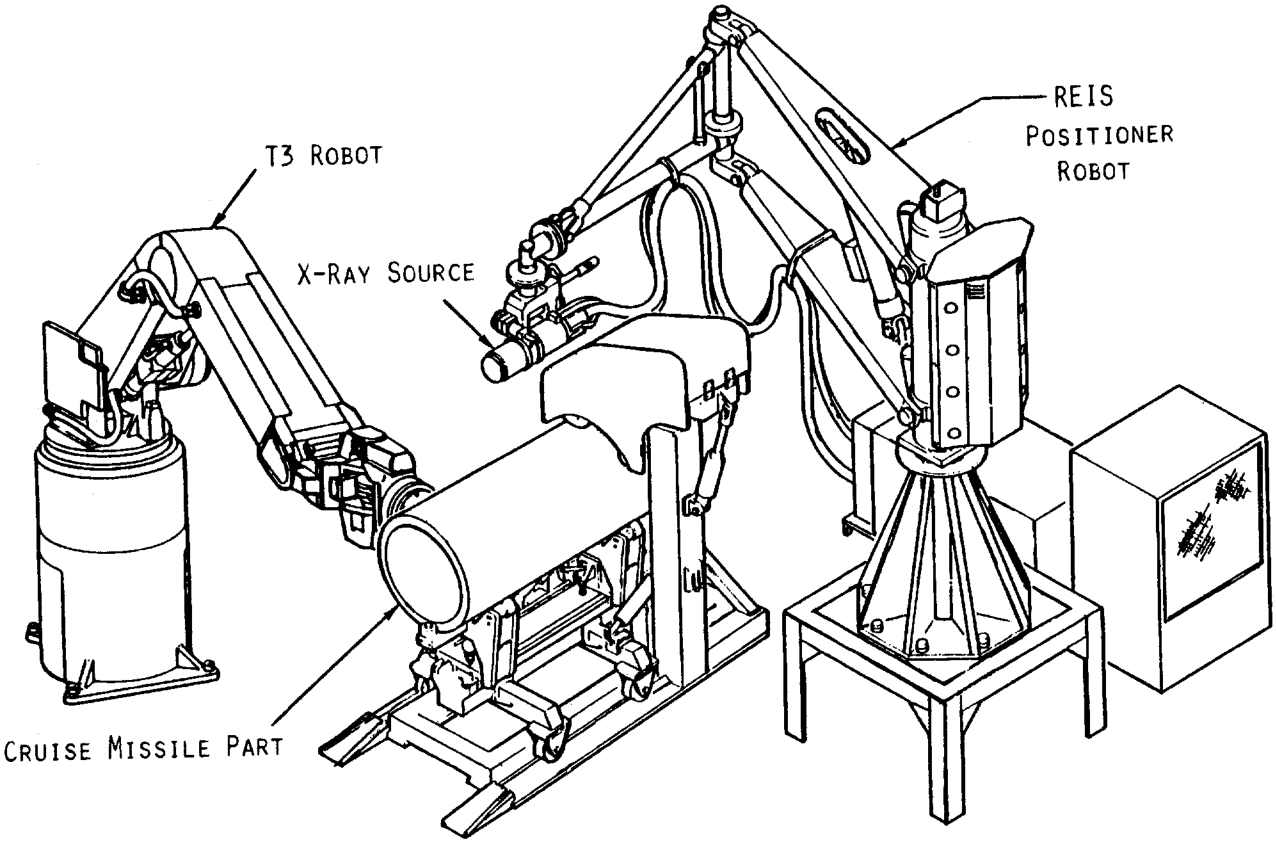
AUTOMATED FUSION WELD INSPECTION SYSTEM

The Automated Fusion Weld Inspection System incorporates robotic and computer control technologies into a workcell for the inspection of cruise missile body weldments. Development of the system, managed by NOSC, was successfully completed in December 1984, and implemented at the General Dynamics (Abilene, TX) cruise missile production line, where it replaced the previous manual radiographic inspection technique.

The Automated Fusion Weld Inspection workcell consists of a motorized assembly cart, two industrial robots, and X-ray photography components. The assembly cart positions and rotates a cruise missile body to the desired location and orientation. Once situated, a Cincinnati Milacron T3 robot maneuvers an X-ray film pack inside the missile body and positions it beside the subject weld. Simultaneously, a REIS robot maneuvers an X-ray source opposite the film pack, external to the body, and an exposure is made. The process is repeated until all welds are photographed, resulting in a total of 140 exposures. Benefits of the system include improved operator safety, faster operation, and a reduction in the original requirement for 230 exposures.

A multi-year enhancement, titled the Real-Time Radiography Weld Inspection System, will substitute linear scanner and fiber optic technology for the present photographic technique. Development, scheduled to begin in FY 86, will focus on the miniaturization and packaging of an X-ray linear scanner, which will replace the film pack on the current system, and be linked to a computer by fiber optics. The computer will be used to control the scanner and store the digitized images. Benefits of the planned enhancement will be reduced cost resulting from the elimination of all photographic processing, and improved inspection quality as a result of computer interpretation of higher contrast images.

AUTOMATED FUSION WELD INSPECTION



- INCORPORATES ROBOTIC AND COMPUTER CONTROL TECHNOLOGY FOR INSPECTION OF MISSILE BODY WELDMENTS
- IMPLEMENTED AT GENERAL DYNAMICS CRUISE MISSILE PRODUCTION LINE
- COMPONENTS:
  - MOTORIZED ASSEMBLY CART
  - INDUSTRIAL ROBOTS
  - -- CINCINNATI MILACRON T3 MANEUVERS X-RAY FILM PACK BESIDE WELD
    -- REIS ROBOT MANEUVERS X-RAY SOURCE OPPOSITE FILM PACK
  - X-RAY PHOTOGRAPHY
- REAL TIME RADIOGRAPHY WELD INSPECTION SYSTEM:
  - MULTI-YEAR ENHANCEMENT
  - MINIATURIZATION AND PACKAGING OF X-RAY LINEAR SCANNER
  - FIBER OPTIC TECHNOLOGY

ROBOTIC STRUCTURAL SHAPES PROCESSING

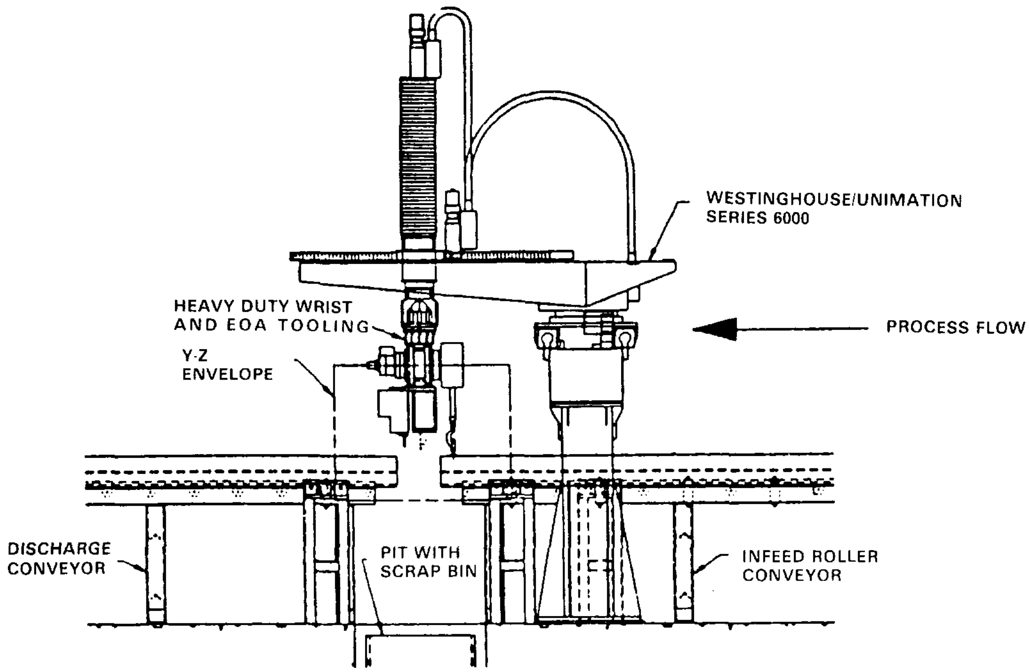
The SEA 05R43 sponsored Robotic Structural Shapes Processing project, managed by Bob Jenkins of DTNSRDC, is designed to address problems associated with the fabrication of structural components used in shipbuilding. Such components are now manually cut from steel and aluminum angles, tees, channels, and other common raw stock. Present methods for marking and cutting of these shapes are highly labor-intensive operations. Conventional oxy-fuel cutting processes used on steel stock leave slag which must be manually removed before finished pieces are palletized for shipment to storage areas. Aluminum stock is presently cut by circular or band saws.

The technical objective of this project is to develop and demonstrate an advanced system incorporating computer-aided-design, robotic marking and cutting, and semi-automatic materials handling. The Robotic Structural Shapes Processing System will contain a Unimate Series 6000 robot on a 50-foot base, with plasma cutting and a programmable precision marking device. The plasma torch will be employed to minimize slag buildup, and can be utilized on both steel and aluminum by simply varying the gas mixture. The stock will be moved through the processing cell with a material handling transport mechanism. A vision system will be used to index the stock, which is then clamped in place for the cutting and marking of the shapes.

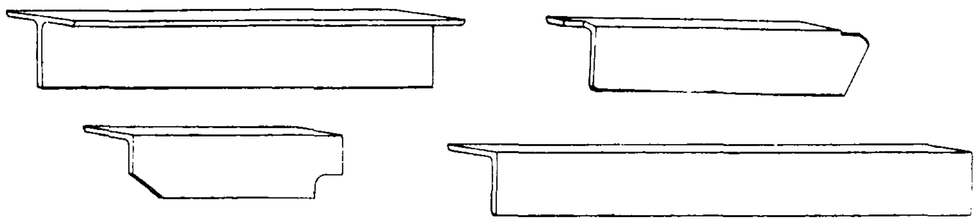
The task of automatically controlling a robotic plasma-cutting workstation is inherently less complex and therefore of lower risk than controlling a welding workstation, because fewer variables are associated with the cutting process. There is only a single piece of stock on which to operate during cutting, as opposed to two or more workpieces to be joined in welding. The desired cuts themselves can be readily defined beforehand in a computer-aided-design (CAD) datafile, both in terms of their configuration and location on the workpiece.

The prime contractor for this effort is Bath Iron Works Corporation. Phase I, completed in April 1983, demonstrated both the feasibility of robotic cutting of the required profile using a plasma torch, and automatic part identification (marking). Westinghouse Electric Corporation is the principal subcontractor to Bath Iron Works for the Phase II effort, initiated in FY 85, which will introduce the CAD input and integrate the semi-automatic material handling system. The functional specifications have been completed for the Numerical Control Support System and the Robotic Processing Cell. Work is well underway on the equipment design and specifications for the material handling system, marking device, robot, cutting torch, and the vision system.

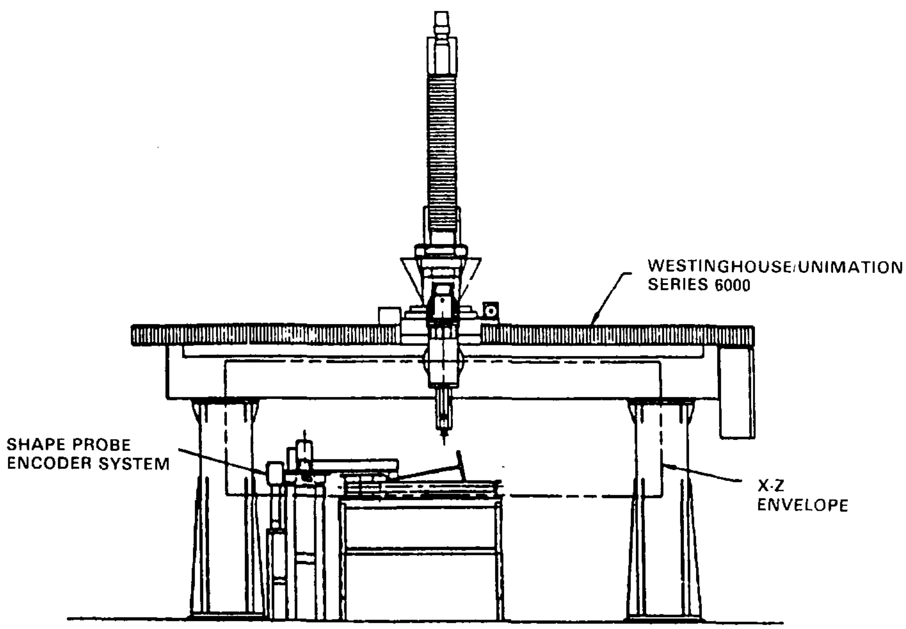
ROBOTIC STRUCTURAL SHAPES PROCESSING



SIDE VIEW OF ROBOT AND MATERIAL CONVEYOR



TYPICAL STRUCTURAL SHAPES



ROBOT AND MATERIAL CONVEYOR: END VIEW

INTEGRATED COMPUTER-AIDED MANUFACTURING OF PROPELLERS

The manufacturing and inspection of propellers involves many costly, labor-intensive processes requiring careful measurement, machining and grinding to achieve the desired quality in the finished product. The Integrated Computer-Aided Manufacturing of Propellers (ICAMP) Project, under direction of Roy Wells, SEA 070A, was initiated to improve propeller quality while reducing manufacturing and inspection costs. ICAMP is designed to accomplish inspection, surface build-up, machining, grinding, and balancing at a single workstation. The first of three installations is underway at Philadelphia Naval Shipyard, with follow-on installations planned for two other naval shipyards. The contractor is Robotic Vision Systems, Inc.

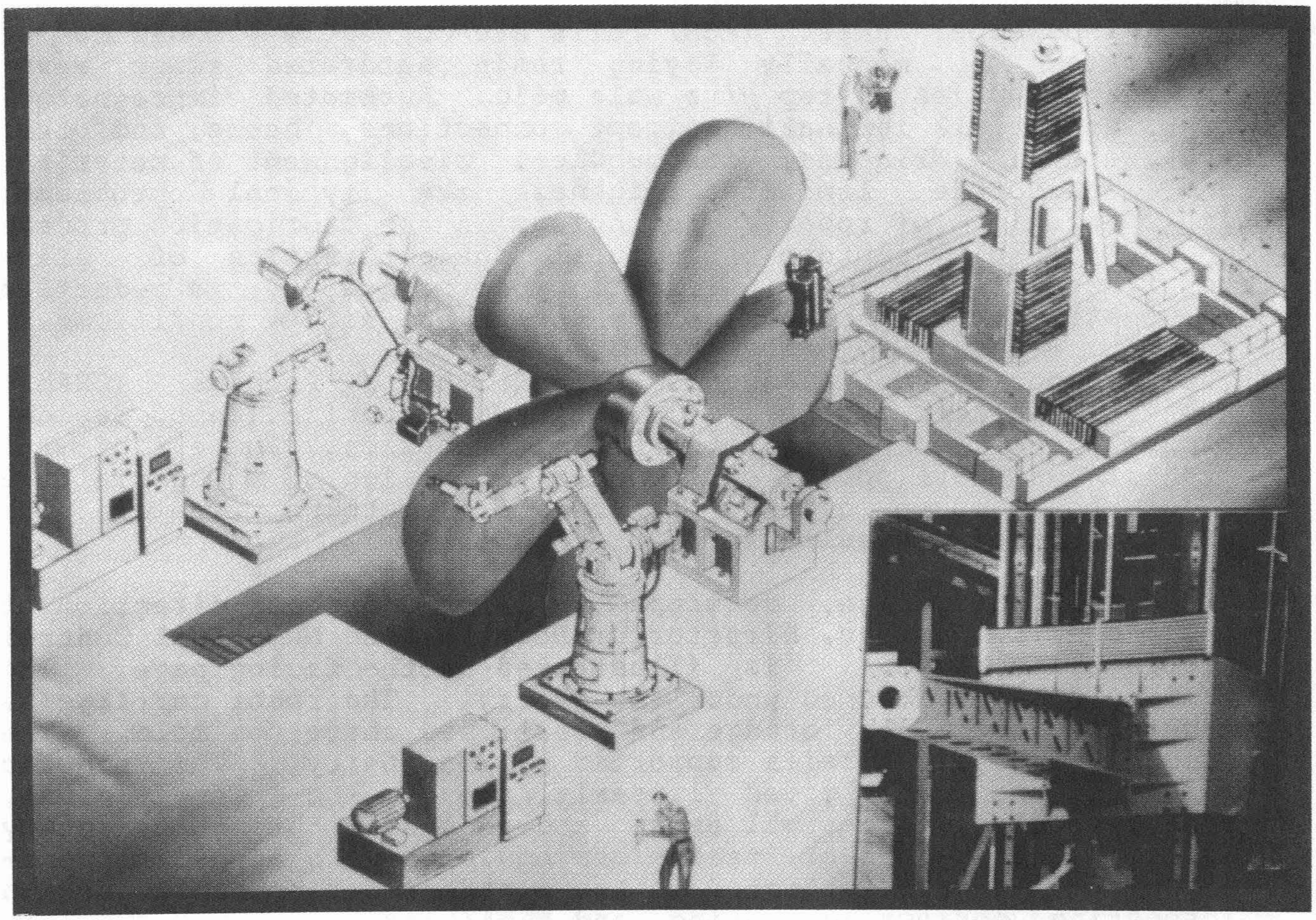
The first phase of the ICAMP effort produced the Propeller Automated Welding System (PAWS), using the RVSI Robo-Sensor to provide seam tracking corrections to the robot performing blade welding and cladding operations. The gas metal arc welding process is used, with tracking over a 0.5 inch range.

The Automated Propeller Optical Measurement System (APOMS), a key element of ICAMP, was developed to provide a high speed optical inspection tool capable of automatically measuring ship's propeller surfaces at low cost, while providing the designer with sufficient reliable data to validate advanced propeller designs. It is designed to collect precise in-process measurements for controlling grinding, welding, and cladding. APOMS integrates a 3-D non-contact measurement system with a custom-designed, precision five-axis robot and a computer network which guides the inspection process and evaluates the data. The measurement sensor is positioned in close proximity to the blade, and oriented to precisely map the surface in three dimensions. A 3-D digital description is created and compared to design specifications, identifying out-of-tolerance areas.

APOMS is capable of scanning and digitizing propeller surfaces at 60 square feet per hour with a measurement resolution exceeding 14,400 samples per square foot, and local measurement accuracy of ± 0.0025 inches.

The Propeller Optical Finishing System (PROFS) machines the propeller to its final specification using design data provided by the computer database. The Propeller Balancing (PROBAL) System performs automated balancing of the propeller. Using APOMS data, the PROBAL System software computes the amount and location of material to be removed, resulting in a balanced propeller meeting design criteria.

INTEGRATED COMPUTER-AIDED MANUFACTURING OF PROPELLERS



- OBJECTIVE:
  - AUTOMATE PROPELLER MANUFACTURING
  - IMPROVE PROPELLER QUALITY
  - REDUCE MANUFACTURING AND INSPECTION COSTS

- ELEMENTS:
  - PROPELLER AUTOMATED WELDING SYSTEM (PAWS)
    - -- SEAM TRACKING
  - AUTOMATED PROPELLER OPTICAL MEASUREMENT SYSTEM (APOMS)
  - PROPELLER OPTICAL FINISHING SYSTEM (PROFS)
  - PROPELLER BALANCING (PROBAL) SYSTEM

COMPOSITE HULL ADVANCED MANUFACTURING PROCESS

Navy Minesweeper Hunter (MSH) hulls are currently planned to be fabricated by manually laying resin saturated glass woven roving/mat plies on top of a male mold. Automated impregnators are used for all lamination except connections, beams, and other small areas. Wrinkles, gas bubbles, misalignment of material, and inaccurate laminate thickness are typical problems. Implementation of robotics technology in the fabrication process could possibly improve structural characteristics of glass reinforced plastic (GRP), lead to improved quality, a reduction in construction costs and improve health and safety conditions.

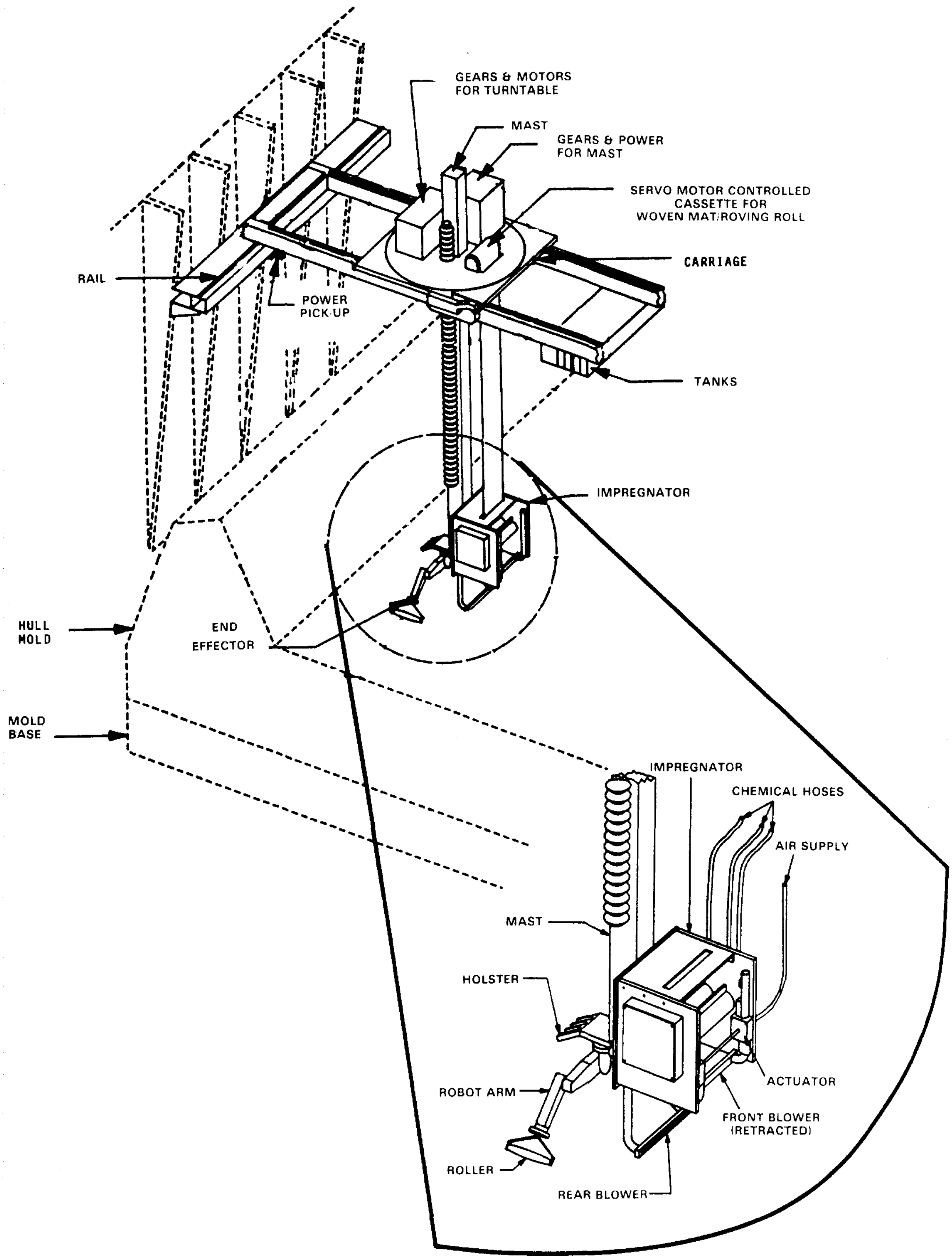
The Composite Hull Advanced Manufacturing Process (CHAMP) project, managed by SEA 55Y13, features a combination of two new technologies: composite materials and robotics. Phase I of the project was development of a conceptual design of a specialized robot to improve quality and reduce processing time in the manufacture of GRP hulls for MSH vessels.

The conceptual design, developed by CASDE under the direction of Dr. John F. Watteau, Director of Robotics and Numerical Control Laboratories at UCLA, is illustrated on the facing page. The hull mold is positioned under the gantry. The robot carriage is mounted on the gantry bridge and positioned above the mold. The bridge moves along rails supported by the gantry. The robotic platform can be moved linearly along the longitudinal, transverse, and vertical axes; and angularly through a rotary axis. A six degree-of-freedom arm equipped with a special end-effector is also attached to the platform for possible use in inspecting, correcting, curing, and finishing.

The robot moves across the hull mold, theoretically depositing layers of impregnated cloth which lie flat, without wrinkles, bubbles or voids. The cloth is fed from the gantry carriage into the impregnator, where it is wetted in a depth-controlled pool of catalyzed polyester resin, and manipulated away from the vertical plane by forward and aft retractable slit blowers. Rollers attached to the robot arm would aid in placement of seams, and press the impregnated cloth against the mold to remove trapped bubbles.

A recent review of the CHAMP project focused on concerns involving sensor feedback for adaptive control, as well as the manipulative dexterity necessary to apply and work resin-impregnated fiberglass using a robotic system. The results of the review will be addressed in Phase II in FY 86 with the issuing of a Request for Proposal (RFP).

COMPOSITE HULL ADVANCED MANUFACTURING PROCESS



TRIDENT HULL CLEANER

The removal of old paint, rust, and scale from ship hulls has been identified as an area of advanced ship repair technology in which robots could play a potential role. For such applications, significant cost savings are projected through increased productivity, with additional benefits derived in terms of worker health and environmental considerations. Conventional grit blasting methods are labor-intensive, involving the erection and later disassembly of elaborate scaffolding to allow access to the work surfaces. Contamination from airborne particulates is hazardous not only to the environment, but also to nearby machinery and equipment. The recovery of accumulated grit from the bottom of the drydock after the operation is a significant part of the overall expense.

The SEA 0703A Trident Hull Cleaner is an example of a semi-autonomous closed-cycle configuration intended to overcome some of these problems. The inertial shot blasting system was developed by Barnes and Reinecke under subcontract to Wheelabrator-Fry, for application on submarine hulls. Recycled steel shot is used to blast the surface, and the abraded material is collected by a vacuum system and stored in a trailer behind the unit for disposal. Initial attempts to implement similar closed-cycle grit blasting systems were plagued by problems associated with premature seal wear out at the interface between the vacuum recovery housing and the hull surface. An innovative design employing a magnetic perimeter seal effectively solves this problem: the abrasive steel shot is drawn into the magnetic gap between the housing perimeter and the hull itself, forming an effective seal.

In operation, the hull cleaner is driven by the operator into position alongside the vessel in the drydock. Once the transport is situated, the manipulator begins to automatically execute a pre-programmed sweep pattern. Servo-controlled manipulator movement causes the end-effector to follow the hull contours, relying on tactile sensor feedback to maintain pre-loaded contact with the hull surface. In this fashion, the workhead tracks up the hull, moves sideways the distance of its own width, and then descends to repeat the operation. After a total of four passes, the operator repositions the transport, and the process is repeated.

The prototype hull cleaner can cover up to 1,000 square feet per hour. The first of two systems has been delivered to the Naval Submarine Base, Bangor, Washington, where it is currently undergoing operational evaluation. Applications for additional systems are being investigated.

TRIDENT HULL CLEANER

CLOSED-CYCLE SHOT BLASTING USING MOBILE PLATFORM DEVELOPED FOR SEA 0703A

- CLOSED-CYCLE SEMI-AUTONOMOUS HULL CLEANING SYSTEM
- TACTILE SENSORS MAINTAIN PRELOADED CONTACT WITH HULL
- EMPLOYS RECYCLED STEEL SHOT TO BLAST SURFACE
- CURRENTLY IN USE AT NAVAL SUBMARINE BASE, BANGOR, WASHINGTON

ROBOT ASSISTED SURFACE PREPARATION AND PAINT PROJECT

The Robot Assisted Surface Preparation and Paint (RASPP) Project is a Manufacturing Technology (MT) effort with Ingalls Shipbuilding to investigate the application of robotics technology for surface preparation and painting. Phase I was intended to perform a survey of available technology, prepare an initial system specification, and perform a baseline economic analysis. The SEA 05R4 project is managed by the Naval Ship Systems Engineering Station (NAVSSES) in Philadelphia, under the direction of Thom Galie.

In February 1985 SEA 90G was requested to conduct a technical review of the RASPP project for NAVSSES and SEA 05R4. A RASPP Working Group of the Robotics Committee was subsequently formed to evaluate the technical aspects of work performed to date. The RASPP Working Group concluded the proposed preliminary design did not establish or support the technical feasibility of a surface preparation and painting system. The Working Group noted that the concept of applying robotics technology to surface preparation has considerable merit, but felt that technical feasibility had not been demonstrated by the contractor. Three of the concerns identified were considered crucial with respect to establishing technical feasibility:

- <u>Sensor Technology</u>: The report inadequately addressed state-of-the-art sensors (or the need for advanced sophisticated sensors) and failed to provide general performance requirements for their development.

- <u>Delivery System Technology</u>: The report minimized problems associated with development of a manipulator capable of positioning the end-effector to perform preparation and painting functions, given load and positioning accuracy requirements.

- <u>Man/Machine Interface</u>: The report lacked an adequate consideration of the scope of requirements for the man/machine interface required in the system being proposed.

The Naval Ship Systems Engineering Station (NAVSSES) participated in the comprehensive review of the Ingalls report and was in agreement with conclusions of the Robotics Committee.

ROBOT ASSISTED SURFACE PREPARATION AND PAINT

- NAVSEA SPONSORED MANUFACTURING TECHNOLOGY PROJECT
- IDENTIFIED AS A HIGH PAYOFF AREA FOR ROBOTIC APPLICATION
- OPTIONS INCLUDED:
  - HULL-CRAWLING ROBOTS
  - EXTENSION ARMS FROM DRYDOCK WALLS
  - MOBILE PLATFORMS
  - OPEN-CYCLE GRIT BLASTING
  - CLOSED-CYCLE SHOT BLASTING
  - LASER-BASED REMOVAL METHODS
- TECHNICAL FEASIBILITY CONCERNS:
  - SENSOR TECHNOLOGY
  - DELIVERY SYSTEM TECHNOLOGY
  - MAN/MACHINE INTERFACE
- CONCLUSIONS:
  - CONCEPT HAS CONSIDERABLE POTENTIAL
  - CONCEPT NOT YET DEMONSTRATED

AUTOMATED MANUFACTURING RESEARCH FACILITY

The National Bureau of Standards (NBS) is developing, with Navy support, an Automated Manufacturing Research Facility (AMRF) to advance the current state of manufacturing technology. The AMRF has become a major national laboratory for technical work related to interfaces and standards for next generation computer-assisted manufacturing, and will be in full operation by the end of 1986. Several workstations in the facility are already used in active research programs by NBS and Navy researchers, industrial researchers, university personnel, and scientists and engineers from other government agencies. The project manager for this effort at NBS is Dr. Phil Nanzetta.

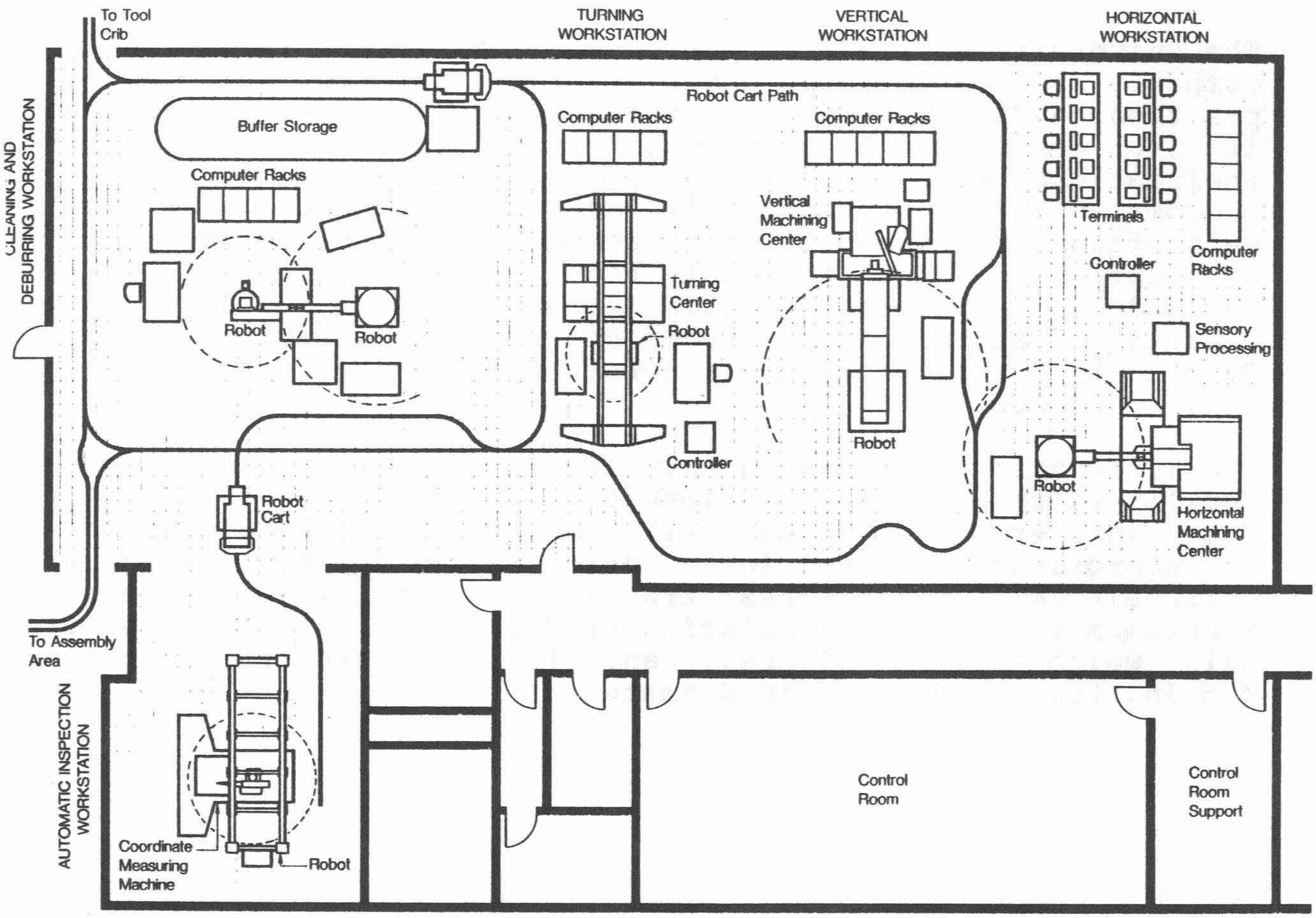
The AMRF supports research in machine tool and robot metrology, sensors and sensory processing, robot safety, robot control, software enhancement of machine tool accuracy, process planning and data preparation for machine tools and robots, parts routing and handling, real-time control of robots and aggregation of devices, workstation control, cell control and materials handling control. It is valuable for studies of interfaces between control modules and among data users.

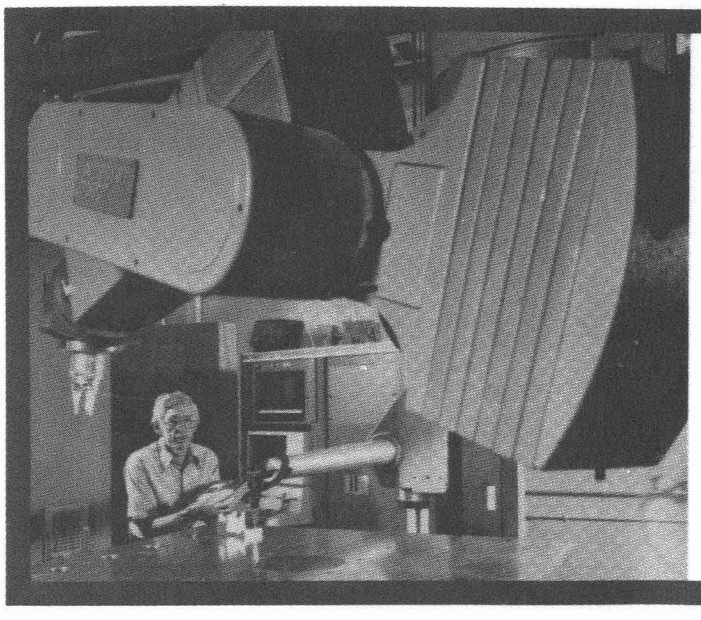
The facility consists of three machining centers, a coordinate measuring machine, and a cleaning and deburring station, each tended by an industrial robot. All components are served by a materials handling system featuring an automated wire-guided vehicle, and an internal buffer storage system for tools, materials, and work in progress. The floor plan of the facility appears on the following page. AMRF's unique approach to modern manufacturing technology uses commercial components where possible. This corresponds to the practical, incremental route to automation followed by small to mid-sized firms.

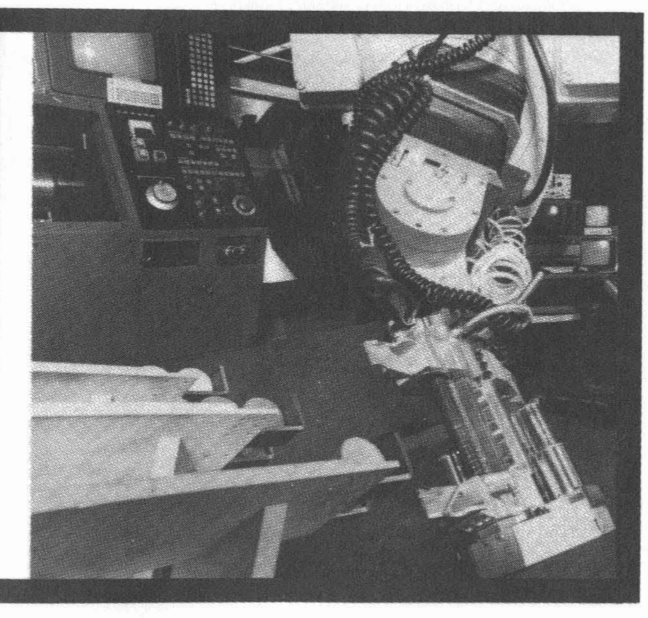
The above components are organized into workstations consisting of a machine tool, its robot, sensors and a workstation controller. Workstation activities are scheduled and coordinated by a cell controller. Two additional control levels provide long-range planning and scheduling, design and engineering services such as process planning, and off-line programming of machine tools and robots.

During public demonstrations held in November 1985, two AMRF workstations performed the machining of five Navy spare parts currently supplied by outside contractors. The Horizontal Workstation fabricated four of the parts, including a valve body and three pipe flanges. The fifth part, a monel valve stem intended for assembly with the valve body, was manufactured by the Turning Workstation. The capability to manufacture such components will be expanded during FY 86 to include 30 Navy spare parts.

AUTOMATED MANUFACTURING RESEARCH FACILITY







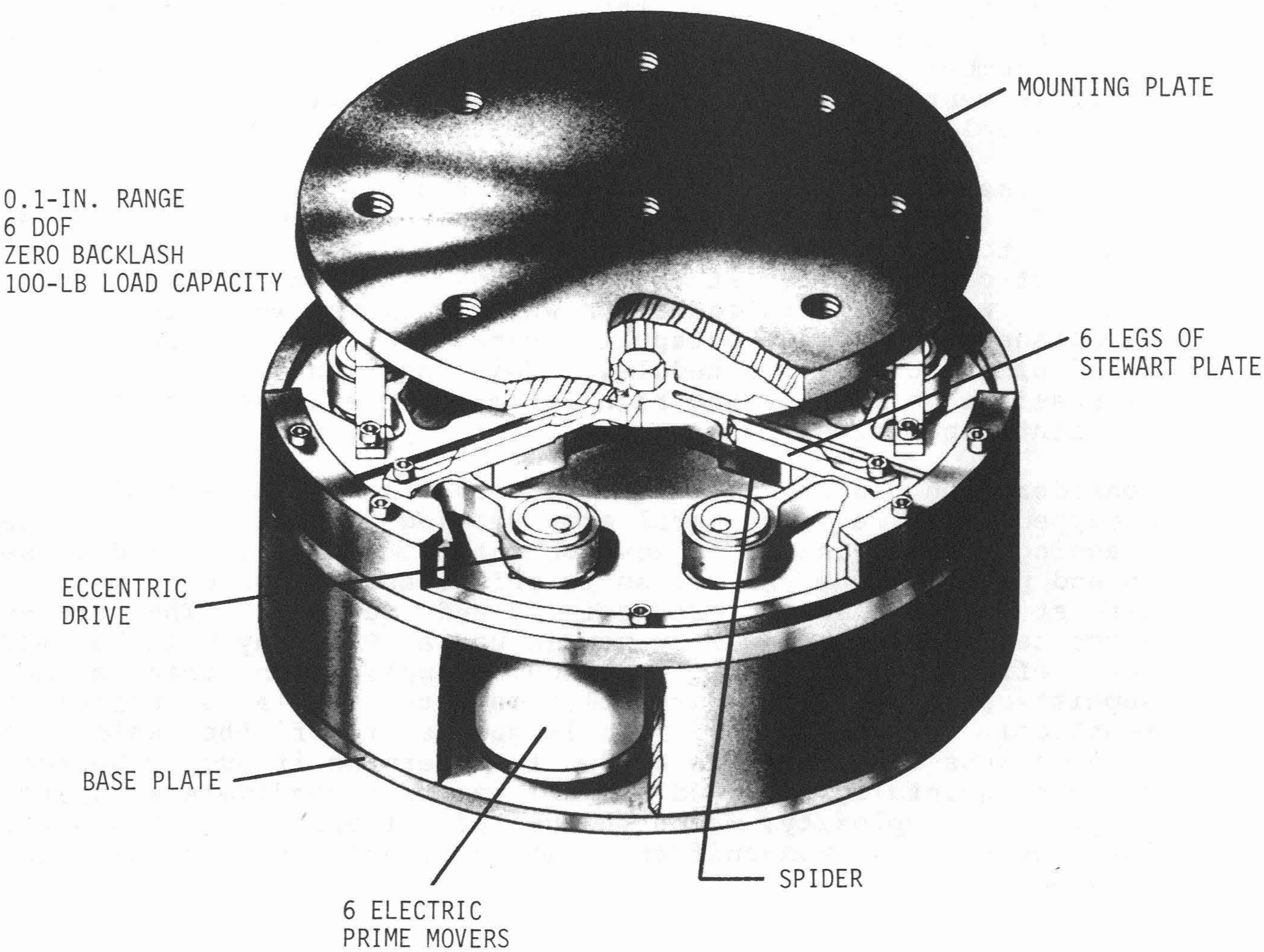
(LEFT) VIEW OF THE INSPECTION WORKSTATION WITH 7-AXIS AMERICAN ROBOT.
(RIGHT) VIEW OF THE TURNING WORKSTATION USING THE NBS MANIPULATOR TO LOAD PARTS IN THE COLLET OF THE TURNING CENTER.

ROBOTIC MICROMANIPULATOR

The University of Texas at Austin (Dr. Del Tesar) is developing a compact, high-precision, compliant manipulator for the fine positioning of robot end-effectors. The objective of the project is to increase the feasibility of high precision robotic applications with a resultant reduction in costs. The Robotic Micromanipulator provides six degrees-of-freedom with high resolution and no backlash. The need for such a device lies in the current design of most robot manipulators. The large payloads and relatively crude motions of these robots prevent their application to high-precision tasks. Installation of the Robotic Micromanipulator will permit fine control of these gross motion devices.

The micromanipulator design envisions a compact, self-contained, module attached to the endplate of an existing robot structure. This vernier system concept will result in positional accuracies of approximately 0.001 in. Motion ranges for the device are extremely small, with linear translations limited to 0.1 in., and a maximum rotational translation of 2 degrees. The manipulator will weigh close to 20 lbs., and will be housed in a structure 4.5 in. thick and 7 in. in diameter.

ROBOTIC MICROMANIPULATOR



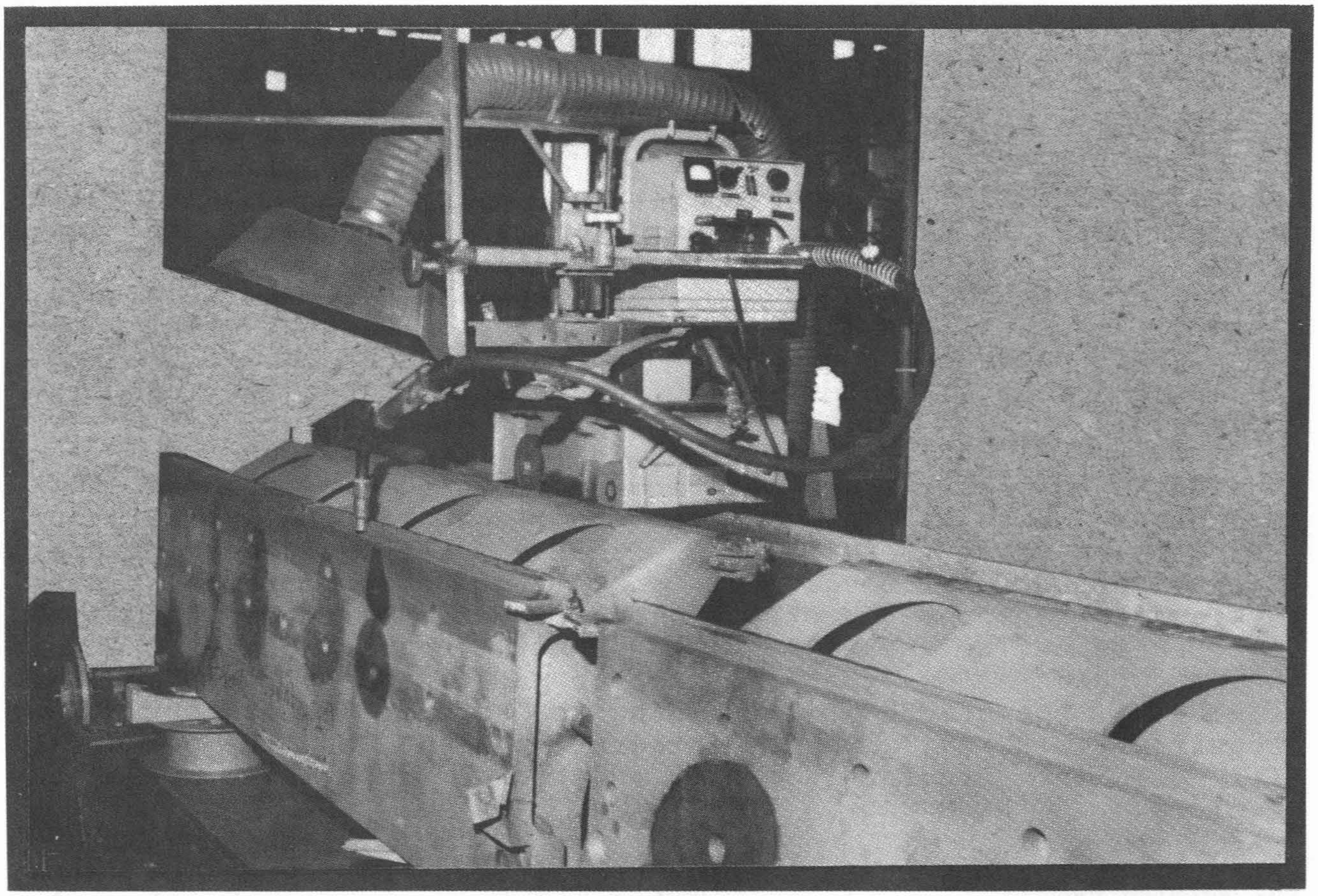
CATAPULT COVER REFURBISHMENT

During regular overhaul, refurbishment of aircraft carrier catapult trough covers routinely involves repetitive disassembly, clad welding of worn surfaces, and machining a large number of similar workpieces to dimensional specifications. A USS Forrestal Class installation typically involves four catapults, to include 380 identical pieces measuring six feet long, and 8 pieces eight feet in length. Welding services for this job involve three eight-hour shifts, seven days a week, for a period of three to six months. Problems encountered to date include the large number of covers, the complexity of the multi-task refurbishment process, cramped working conditions, and shortages of material, equipment, and personnel.

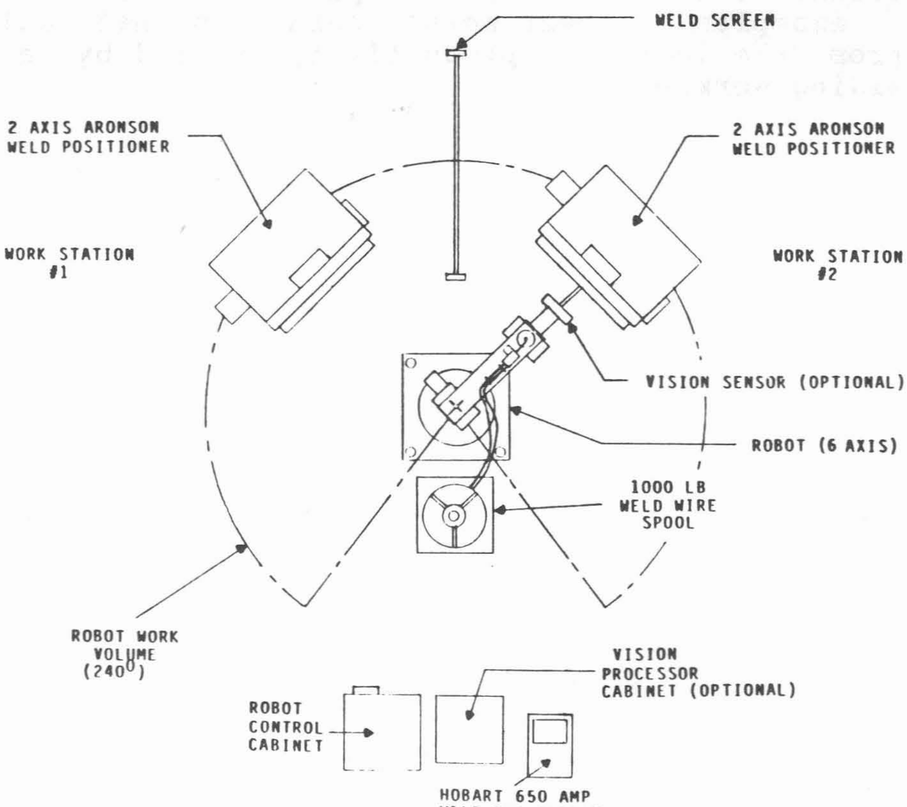
An automated gas metal arc welding system employing a rail-mounted tractor has been developed at Puget Sound Naval Shipyard (PSNS) for use during one of the first Class A overhauls of aircraft carrier catapult track covers. This capability, coupled with a workcell configuration which allows work to proceed simultaneously on two catapult covers, has enabled PSNS to stay ahead of the overhaul schedule. This "hard automation" approach is possible because of the high volume, repetitive nature of the straight-line welds.

Consideration is being given to introducing an industrial robot, equipped with a gas metal arc welding capability and seam tracking system, into this environment. The time required to set up and program from ship class to ship class, however, must be off-set by increased productivity and quality. The present automated welding capability now in use at PSNS may well be more cost effective for this particular application than a more sophisticated robotic workcell, due to the large number of identical workpieces and the linear nature of the welds. An applications assessment is needed to determine if such a workcell could be gainfully employed as well on other candidate workpieces of greater complexity, where the use of a flexible robotic system for low-volume, non-uniform welding operations is certainly merited.

CATAPULT COVER REFURBISHMENT



EXISTING AUTOMATED GMAW SYSTEM AT PSNS FOR CATAPULT COVER REFURBISHMENT



PROPOSED ROBOTIC WORKCELL FOR GMAW WELDING APPLICATIONS

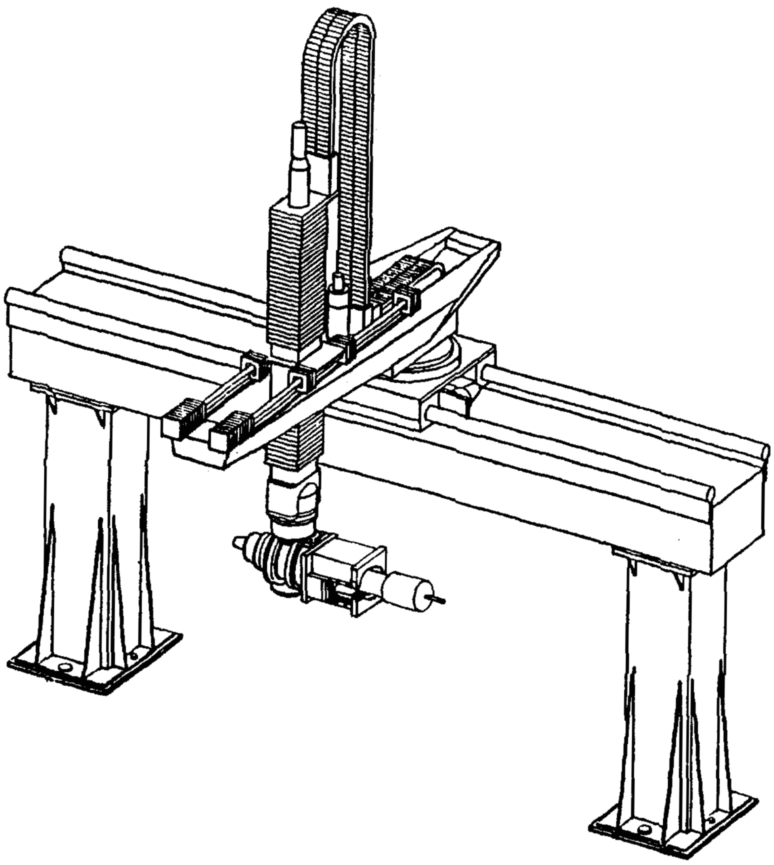
ROBOTIC SHEET METAL WELDING SYSTEM

Planning has begun on a candidate SEA 070A project, selected from a broad list of potential naval shipyard applications, to automate certain welding operations employed in sheet metal shops. Careful thought must be given to the prospects for good return on investment when investigating the automation of processes employed in low-volume, unstructured environments. Repetitive operations similar to those found in sheet metal shops are good potential candidates for the application of second-generation robotic systems employing sensor feedback for adaptive control.

Various combinations of positioning tables, robots, and weld processes must be investigated to maximize the utility of selected systems for dealing with a variety of work items. Consideration will be given to installing an appropriate vision system to compensate for workpiece deviations within specified tolerances. The use of multiple workstations is another option which would allow the simultaneous performance of set up and fixturing operations while welding to enhance throughput. The required fixturing, systems integration needs, and the potential for off-line programming are additional important areas to explore.

Sheet metal shops at Puget Sound Naval Shipyard sometimes work three shifts, seven days a week fabricating locker berths. In these quantities, the fabrication of repetitive items such as locker berths, ventilation ducts, panel doors and frames are attractive examples of sheet metal operations that could benefit greatly from the increased productivity offered by a flexible robotic welding workcell.

ROBOTIC SHEET METAL WELDING SYSTEM



- PLANS ARE UNDERWAY TO DEVELOP A ROBOTIC WELDING CAPABILITY IN NAVAL SHIPYARD SHEET METAL SHOPS
- CANDIDATE APPLICATIONS INCLUDE FABRICATION OF:
  - LOCKER BERTHS
  - VENTILATION DUCTS
  - PANEL DOORS AND FRAMES
- THE PRESENT MANUAL FABRICATION OF LOCKER BERTHS IS HIGHLY LABOR INTENSIVE
- IMPORTANT CONSIDERATIONS:
  - INTEGRATION OF POSITIONING TABLES, VISION SYSTEMS, ROBOTS, AND WELDING SYSTEMS
  - UTILIZATION OF MULTIPLE WORK STATIONS
  - APPLICATION OF OFF-LINE PROGRAMMING

AUTOMATED THERMAL SPRAY WORKCELL

Application of flame-sprayed coatings is often used in the refurbishment of machine parts, such as valve components, rotating machinery shafts, turbine casings, and packing sleeves. The Automated Thermal Spray System is an effort to increase productivity, improve quality, and reduce harmful working conditions currently associated with conventional spray methods.

Existing manually-operated equipment at Puget Sound Naval Shipyard is now in use at maximum capacity over two 12-hour shifts, seven days a week, and the workload is projected to double over the next two years. The present system poses significant health hazards to the operator, and costs of meeting NAVOSH requirements are considerable. Process parameters such as arc current and voltage, preheat temperature, and plasma gas pressure are initially set, and remain constant throughout the operation with no adaptive control possible.

The installation of an automated system employing feedback sensors and a robotic end-effector would allow such parameters to be monitored and controlled in real time, eliminate time loss associated with maintaining temperature and measuring process parameters, and remove the operator from a hazardous environment.

Important considerations in applying robotic technology to this need include determination of effort required for setup and programming, and identification of the nature and repeatability of machine parts to be refurbished. At present, a technical review of an Air Force Manufacturing Technology automated thermal spray system is being conducted at Puget Sound Naval Shipyard to ascertain applicability to shipyard operations. Upon completion of this assessment, efforts will be initiated to procure appropriate equipment to implement an automated thermal spray workcell.

AUTOMATED THERMAL SPRAY WORKCELL

- APPLICATION IN REFURBISHMENT OF MACHINE PARTS:
  - VALVE STEMS
  - SHAFTS (ROTATING MACHINERY)
  - TURBINE AND PUMP CASINGS
  - PACKING SLEEVES
- PROBLEMS WITH CURRENT MANUAL OPERATION:
  - WORKLOAD PROJECTED TO DOUBLE IN TWO YEARS
  - POOR REPEATABILITY, PROCESS CONTROL
  - POSES HEALTH HAZARDS TO OPERATOR
  - COST OF MEETING NAVOSH REQUIREMENTS CONSIDERABLE
- APPROACH:
  - INSTALL AUTOMATED ROBOTIC SPRAY SYSTEM
  - MONITOR/CONTROL PARAMETERS IN REAL TIME

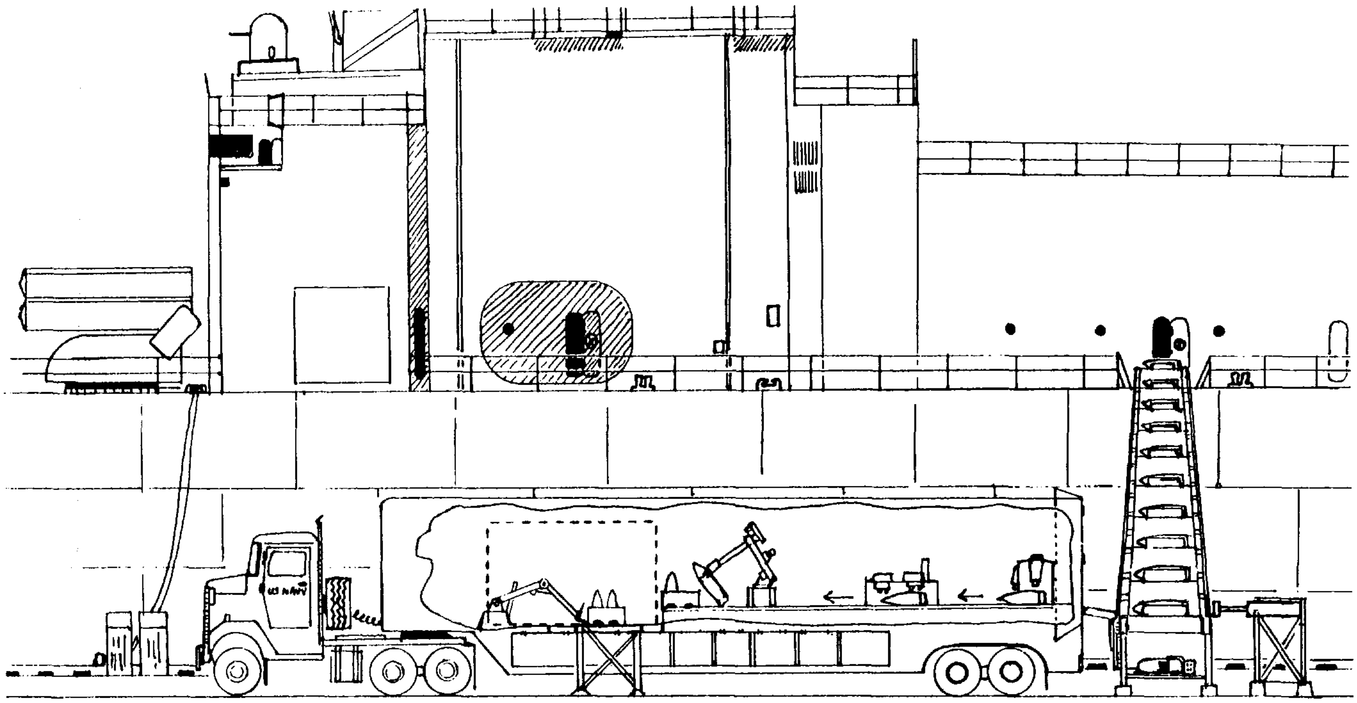
AMMUNITION OFF-LOADING AND INSPECTION SYSTEM

The off-loading of projectiles from naval combatants is a time consuming process which offers significant potential for improvements in productivity as well as safety through appropriate use of automation. Conventional practices involve placing the projectiles into a skid box, which is then transferred by crane to the pier for transportation to a remote inspection point. Projectiles are then classified according to the degree of refurbishment required.

A concept developed by Captain William F. Cadow, SEA 064, calls for the use of a relocatable off-loading and inspection capability housed in a trailer that could be driven into place alongside the vessel. A material transport conveyor would extend from this trailer to the deck of the ship as shown in the artist's concept on the facing page. Projectiles would be marked with a circular bar code that could be used to identify recalled lots, facilitating computer-controlled inventory management. Upon passing through the bar code reader, the projectile would next enter a non-contact measurement station, where critical mechanical dimensions would be checked, and out-of-tolerance conditions flagged. The projectile would then pass through a real-time inspection station designed to detect the presence of corrosion or other conditions warranting refurbishment.

An automated "pick-and-place" robot at the end of the material conveyor would then palletize the projectiles accordingly for rework, refurbishment, or reissue, based on the inspection results. For safety purposes, any such operations requiring actual physical contact with the ordnance would take place at a remote site. Significant productivity gains are projected through the use of this non-contact inspection technology, in that projectiles not in need of refurbishment or rework can be immediately reissued on site. The automated inventory tracking made possible by bar code marking of the individual ordnance items is expected to yield substantial improvements in efficiency as well.

AMMUNITION OFF-LOADING AND INSPECTION SYSTEM



- CONCEPT FOR RELOCATABLE OFF-LOADING AND INSPECTION CAPABILITY
- POTENTIAL FOR SIGNIFICANT PRODUCTIVITY IMPROVEMENT THROUGH AUTOMATION
- BARCODING FACILITATES COMPUTER CONTROLLED INVENTORY
- NON-CONTACT INSPECTION AND MEASUREMENT
- ROBOTIC PALLETIZING
- OPERATIONS REQUIRING PHYSICAL CONTACT CONDUCTED AT REMOTE SITE

SHIP SURFACE SCANNER

The successful planning and execution of ship overhaul and repair activities is dependent on the availability of accurate measurements of ship structural components. Present methods necessitate large survey teams to gather the required dimensional information using standard measuring techniques (tapes, rulers, etc.), with resulting data manually recorded and stored. This approach is labor intensive and costly. It is also restrictive in terms of the completeness and thoroughness of the survey, as well as the accuracy of the data collected. In addition, the resulting format does not permit shipyard personnel to visualize the measurement information.

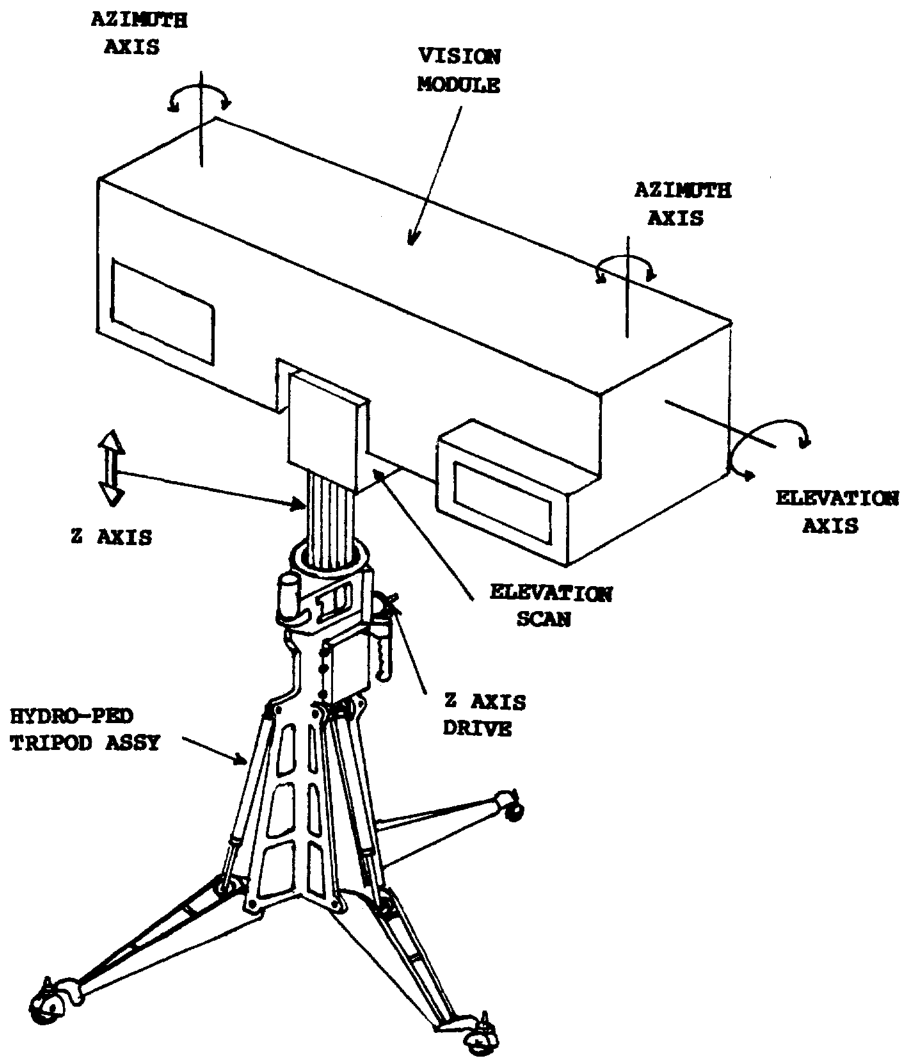
The Ship Surface Scanner is designed to gather physical survey data on the interior of a ship and convert the information for use with a computer-aided design system. This will provide high-resolution data for generating graphic displays and "as built" drawings of ship compartments. These displays and drawings will reduce the required man-hours for documentation, planning and support of the scheduled shipyard repair activities, and allow for pre-fabrication of structural assemblies to be installed during overhauls.

The technical approach incorporates a tripod-mounted scanning sensor utilizing a laser projector and a solid state receiver. The sensor scans in elevation and azimuth, and generates a database that is synthesized with scan data from two other sensors (or the same sensor placed in several positions) for complete 360 degree three-dimensional data acquisition.

Phases I and II of this project have been completed and include the design, development, fabrication, and testing of one prototype model. In Phase III, a second ship sensor unit will be fabricated, and software will be developed to incorporate the data from both Processor Units to register their position relative to each other, and to provide a real-time display indicating the compartment areas that have been scanned.

In Phase IV, a technical and engineering analysis will be conducted to determine the practicality of improving the accuracy of the Ship Scanning system sensor and applying it to the digitizing of propeller blades on ships in drydock. In Phase V, a third sensor unit will be fabricated and tested and the additional software developed to further process data into the format required for input into a computer-aided-design (CAD) system. Finally in Phase VI, the CAD interface for the shipyard readout and display function will be developed and tested.

SHIP SURFACE SCANNER



SENSOR ASSEMBLY

- DESIGNED TO GATHER SURVEY DATA ON INTERIOR OF SHIP AND CONVERT FOR USE WITH COMPUTER-AIDED-DESIGN SYSTEM
- PROVIDE DATA TO GENERATE "AS BUILT" DRAWINGS
- TECHNICAL APPROACH:
  - TRIPOD-MOUNTED SENSOR SCANS ELEVATION AND AZIMUTH
  - PROVIDES 360 DEGREE 3-D DATA AQUISITION
- DESIGN, DEVELOPMENT, FABRICATION AND TESTING OF FIRST PROTOTYPE COMPLETE

NAVAL ORDNANCE

The Manufacturing Technology Division of the Naval Ordnance Station (NAVORDSTA), Indian Head, Maryland, has several related projects using robotics and automated systems to support operations designed to rework Cartridge Actuated Devices, used primarily in aircrew escape systems. This Manufacturing Technology project is being conducted under the direction of Glenn Campbell, Code 5111, in support of NAVAIR and the U.S. Air Force.

The process involves the disassembly and removal of the cartridge (which contains Class III explosives), the refurbishment of metal parts, and the reassembly of the Cartridge Actuated Device. The four workstations used in the process are described below.

Assembly/Disassembly Workstation - This workstation will provide automatic loading, assembly/disassembly and unloading of Cartridge Actuated Devices for rework. The Cartridge Actuated Device is fed into the workstation, where it is disassembled, the cartridge removed, and reassembled after rework. The project start date was initially set for April 1985 with hardware delivery scheduled for April 1986. Completion of the prototype was planned for June 1986. The hardware specification and procurement actions have not been completed, however, due to funding delays.

Residual Magnetism Workstation - The Residual Magnetism Workstation is an effort designed to replace a highly labor intensive demagnetization and inspection procedure. It will provide automatic demagnetization, magnetization testing, and unloading of the reworked Cartridge Actuated Devices. The project is currently in the procurement stage, with the design of the demagnetization process the initial step in a phased development approach.

Parts Loading Robot - The Parts Loading Robot, currently in operation at the Naval Ordnance Station, is a pneumatic robot used for loading existing reworked operational equipment into the deburring station. It is used primarily for the loading and unloading of the larger lot sizes which vary from approximately 50 to 5000 pieces.

Thread Chasing Robotic System - NAVORDSTA is planning a robotic system specifically for automatic thread chasing and inspection of reworked Cartridge Actuated Devices. A feasibility study has been completed and an RFP has been generated.

NAVAL ORDNANCE REFURBISHMENT

- ROBOTICS AND AUTOMATED SYSTEMS SUPPORT FOR REWORK OF CARTRIDGE ACTUATED DEVICES

- PROCESS INCLUDES:

  - DISASSEMBLY OF CARTRIDGE ACTUATED DEVICE
  - REMOVAL OF CARTRIDGE CONTAINING CLASS III EXPLOSIVES
  - REFURBISHMENT OF METAL PARTS
  - REASSEMBLY

- FOUR WORKSTATIONS:

  - ASSEMBLY/DISASSEMBLY WORKSTATION:
    - AUTOMATIC LOADING, ASSEMBLY/DISASSEMBLY AND UNLOADING
    - CONCEPTUAL DESIGN COMPLETE

  - RESIDUAL MAGNETISM WORKSTATION:
    - REPLACES LABOR INTENSIVE INSPECTION
    - AUTOMATIC DEMAGNETIZATION, MAGNETIZATION TESTING, AND UNLOADING
    - PROJECT IN PROCUREMENT STAGE

  - PARTS LOADING ROBOT:
    - PNEUMATIC ROBOT CURRENTLY IN OPERATION
    - PRIMARILY USED FOR LOADING AND UNLOADING DEBURRING STATION

  - ROBOTIC SYSTEM DESIGNED FOR:
    - AUTOMATIC THREAD CHASING
    - INSPECTION

NAVAL ORDNANCE

Robotic Vision Inspection System

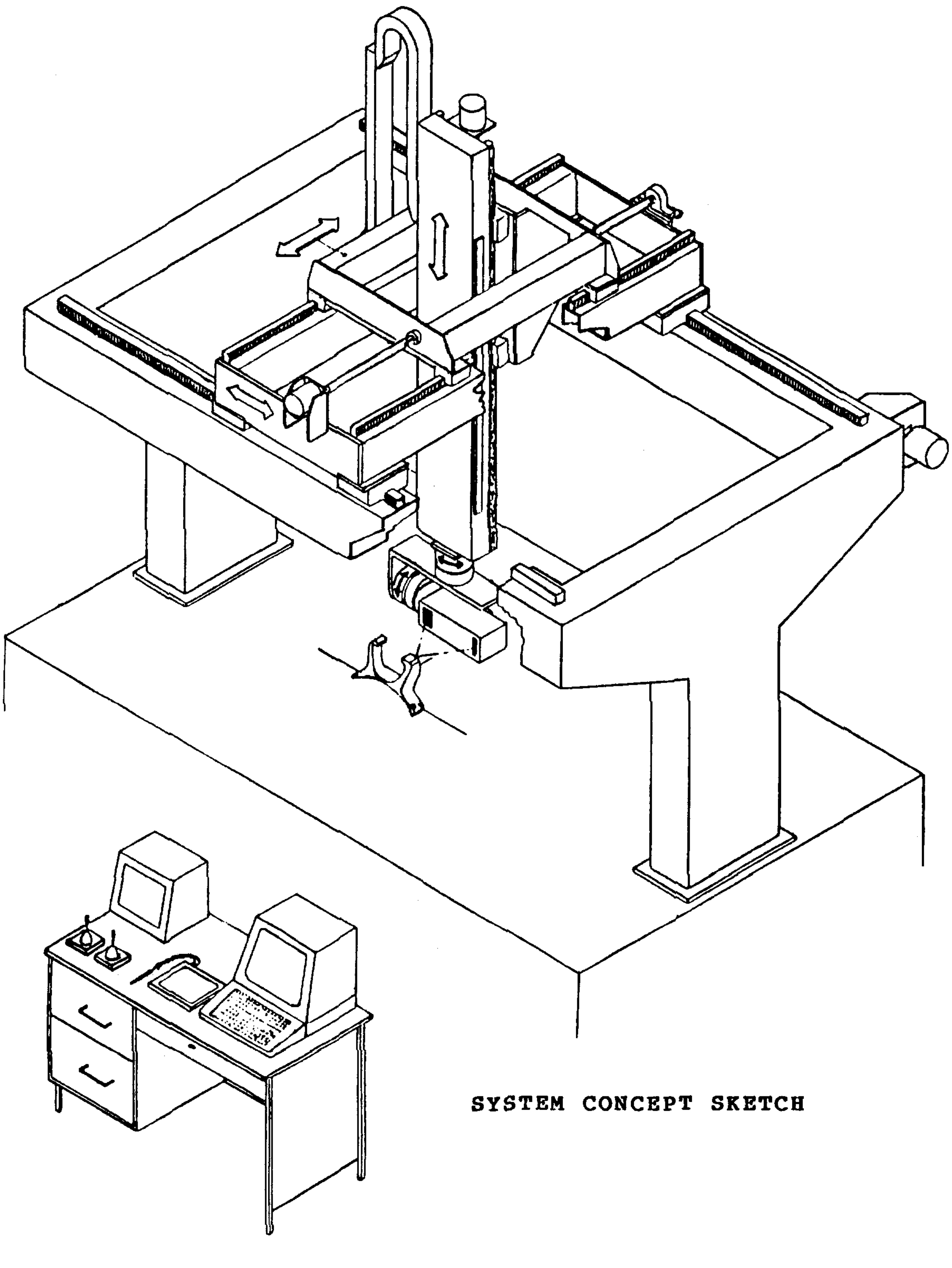
The inspection operation at the Naval Ordnance Station (NAVORDSTA), Indian Head, MD, processes approximately 3,000 lots of small parts per year using a primarily manual process. Sample sizes range from 1 to 150 pieces, and certain critical parts call for 100% inspection.

The Robotic Vision Inspection System is designed to provide automatic inspection of the incoming metal parts for use in assembly operations at NAVORDSTA. The effort, managed by Eugene Stefko, NAVORDSTA Code 604, was initiated in January 1985 and the Phase I Feasibility Study was completed by RVSI during 1985. Plans are proceeding for procurement in FY 87.

A feasibility study will be initiated in July 1986 to investigate integrating the Robotic Vision Inspection System with a real-time X-ray capability. The final phase will incorporate the ability to generate engineering drawings from sample parts.

The Robotic Vision Inspection System will be capable of inspecting parts in a 2.5 ft. x 2.5 ft. x 2.5 ft. envelope. The part supporting surface plate and its structure will be rigid enough to support heavy boxes and the system shall be operated in environments similar to those in machine shops and shipping/receiving rooms. The normal accuracy of the system will be 0.001 inch within a 6 inch spherical radius and an additional 0.001 inch per 12 inches in distance. A high accuracy mode providing target resolution of .0001 inch shall be sought for dimensions of 6 inches or less. The system shall measure all external surfaces, and internal surfaces to a depth of one-half the diameter of the opening, and be able to scan a 4 in. x 4 in. x 4 in. part in 2 minutes or less.

ROBOTIC VISION INSPECTION SYSTEM



SYSTEM CONCEPT SKETCH

NAVAL ORDNANCE

MK-27 Fuze Inspection System

The Naval Weapons Station, Concord, CA is developing a robotic inspection system, using a "pick and place" robot and an X-ray imaging system, to inspect MK-27 Fuzes in batches. This procedure decreases the overall inspection time by reducing the number of times the X-ray enclosure must be entered, and the number of times the inspected items must be individually handled. The robot is a pneumatic four-axis unit driven by an 80-120 PSI shop air supply. It is suspended above a stepping motor driven X-ray table with a rotary platform positioned in front of the imaging screen. Two racks (accepted and rejected) are used to hold the inspected items.

Items are initially positioned in the enclosure on a tray containing 32 units. The X-ray table orients the item at the robot's pick-up point. The robot then sets the item on the rotary platform. The item is X-rayed and, depending on the decision, the robot removes the item from the rotary platform and places it in the accept or reject rack. The robot uses two grippers and picks up one item while another is being inspected.

The project was initiated in September 1985, with an estimated completion date of February 1987. The project manager is James Prindiville, Naval Weapons Station, Code 334, Concord, CA.

Infrared Test System

The Naval Weapons Support Center, Crane, IN, is developing an Infrared Test System which measures and records performance parameters of various decoy flares being evaluated for production acceptance. The robotic system employed will load the flares into test fixtures. Initiated in April 1985, the estimated completion date is December 1986. The point of contact for the project is Jack Kramer, Code 30232.

NAVAL ORDNANCE

MK-27 FUZE INSPECTION SYSTEM

- NAVAL WEAPONS STATION, CONCORD, IS DEVELOPING A BATCH INSPECTION SYSTEM TO INSPECT MK-27 FUZES

- INITIATED IN SEPTEMBER 1985

- THE SYSTEM INCLUDES:
  - A PNEUMATIC FOUR-AXIS ROBOT
  - AN X-RAY IMAGING SYSTEM

- THE PROCEDURE RESULTS IN:
  - REDUCED HANDLING TIME
  - DECREASED INSPECTION TIME

- ESTIMATED COMPLETION DATE IS FEBRUARY 1987

INFRARED TEST SYSTEM

- UNDER DEVELOPMENT BY NAVAL WEAPONS SUPPORT CENTER, CRANE

- MEASURES AND RECORDS PERFORMANCE PARAMETERS OF DECOY FLARES

- PROJECT INITIATED - APRIL 1985

- ESTIMATED COMPLETION DATE - DECEMBER 1986

EXPLOSIVE ORDNANCE DISPOSAL

For over ten years, Naval Explosive Ordnance Disposal Technology Center (NAVEODTECHCEN), Indian Head, MD, has had an ongoing program to develop remote control and teleoperated systems for neutralizing explosive devices. The program is concerned with land- and ship-based systems as well as underwater systems.

The EOD land-based efforts are managed by CDR Stan Denham, SEA 0696, and are under the technical direction of John R. Butler, Head, Mechanical Engineering, NAVEODTECHCEN. These primarily teleoperated systems, designed to enhance EOD capabilities, include:

(1) Remotely Operated Vehicle for Emplacement and Reconnaissance (ROVER)
(2) Semi-Autonomous Mobile System for Ordnance Neutralization (SAMSON)
(3) Remote Control Reconnaissance Monitor (ReCoRM)
(4) Remote Interface Concept
(5) Heavy Equipment Remote Control (HERC) System
(6) English Language Robot Communication (ROBCOM)
(7) 3-D Vision--Human Operators
(8) Guided Robotic Disassembly System (GRIDS)
(9) Surface/Subsurface Clearance Vehicle (SSCV)
(10) Borehole Location/Detection System

NAVEODTECHCEN has two projects underway to develop, evaluate, and field test remote controlled underwater platforms for locating and neutralizing explosive objects. The systems include:

(1) The Advanced Development Remotely Operated Vehicle (ADROV)
(2) PLUTO

Each system is designed to be operated from small boats by EOD personnel. John J. Pennella, Head, Underwater Project Division, manages the technical development effort of ADROV and PLUTO. ADROV is sponsored by SEA 06G6 (LCDR C. Bernier). PLUTO is sponsored by SEA 06G6 (CDR Stan Denham).

EXPLOSIVE ORDNANCE DISPOSAL

LAND- AND SHIP-BASED SYSTEMS

- REMOTELY OPERATED VEHICLE FOR EMPLACEMENT AND RECONNAISSANCE (ROVER)
- SEMI-AUTONOMOUS MOBILE SYSTEM FOR ORDNANCE NEUTRALIZATION (SAMSON)
- REMOTE CONTROL RECONNAISSANCE MONITOR (ReCoRM)
- REMOTE INTERFACE CONCEPT
- REMOTELY OPERATED MOBILE EXCAVATOR (ROME)
- HEAVY EQUIPMENT REMOTE CONTROL (HERC) SYSTEM
- ENGLISH LANGUAGE ROBOT COMMUNICATION (ROBCOM)
- 3-D VISION--HUMAN OPERATORS
- GUIDED ROBOTIC DISASSEMBLY SYSTEM (GRIDS)
- SURFACE/SUBSURFACE CLEARANCE VEHICLE (SSCV)
- BOREHOLE LOCATION/DETECTION SYSTEM

UNDERWATER SYSTEMS

- ADVANCED DEVELOPMENT REMOTELY OPERATED VEHICLE (ADROV)
- PLUTO

EXPLOSIVE ORDNANCE DISPOSAL

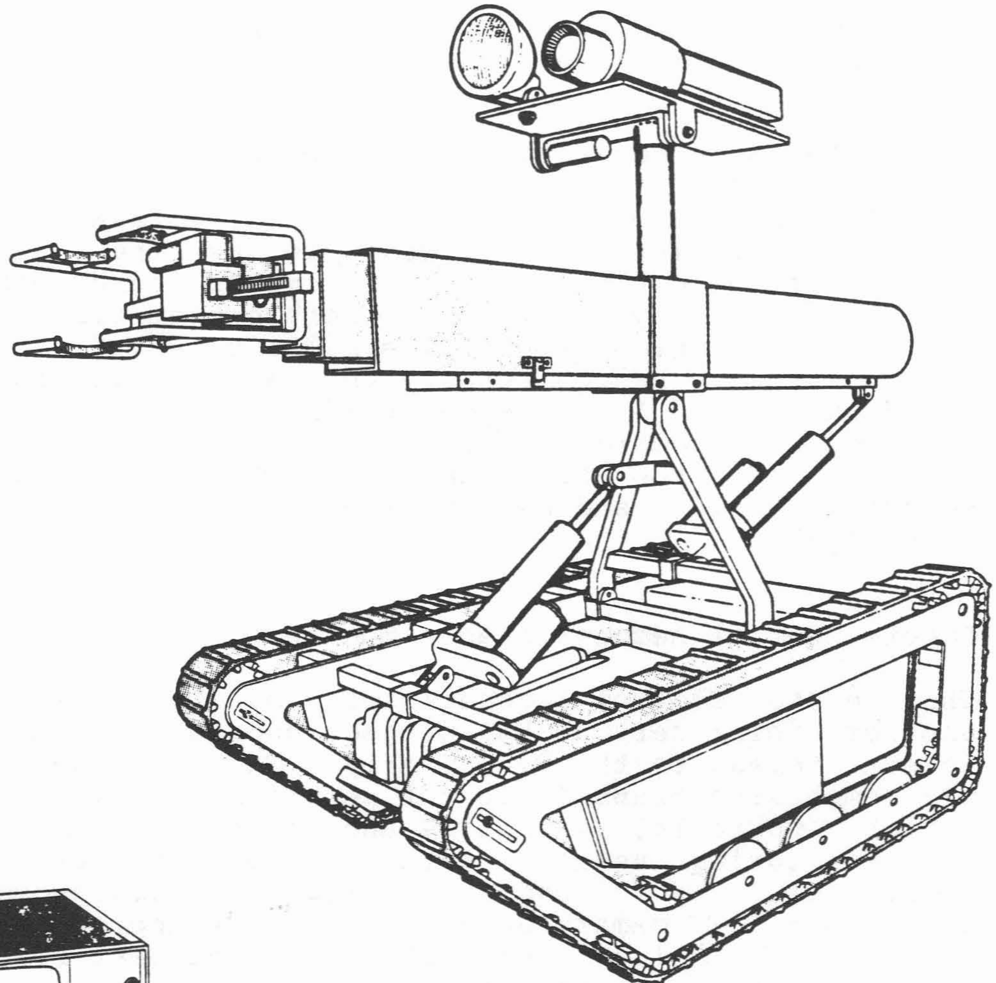
Remotely Operated Vehicle for Emplacement and Reconnaissance

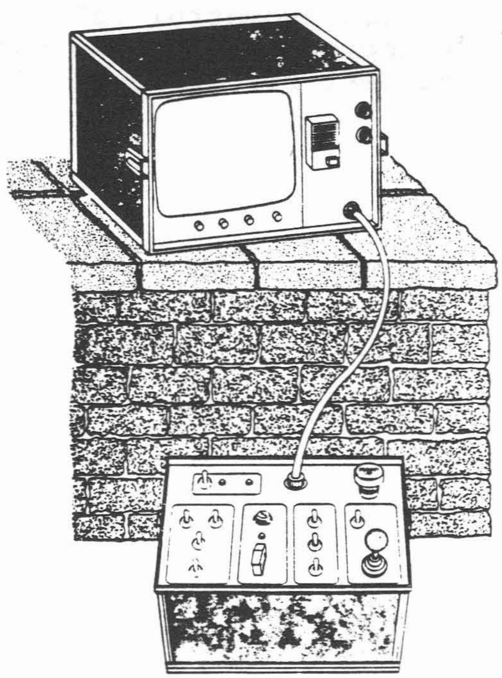
The Remotely Operated Vehicle for Emplacement and Reconnaissance (ROVER) is a NAVEODTECHCEN program to develop a low cost, teleoperated vehicle for use by EOD personnel in neutralizing unexploded ordnance at a safe standoff distance, and for conducting reconnaissance. ROVER has the capability to be controlled by both radio and cable, with an onboard video camera providing visual feedback to the remote operator. Most of the control functions are microprocessor-based. ROVER is a 450 pound, battery powered vehicle, equipped with a nine foot extending arm and a three degree-of-freedom gripper. It has a two-to-four hour operational endurance.

ROVER has emerged as a result of technology developed over the previous ten-year period. In FY 83, a transfer to 6.3 occurred, and Foster Miller was awarded a contract to produce three advanced development ROVER units. The first prototype was delivered in April 1985, and is currently in the technical evaluation stage. Initial tests were conducted by the contractor, with concentration on environmental and reliability issues. Evaluation continues at NAVEODTECHCEN, with current efforts concentrated on mission profile testing.

During FY 85, an EOD Robotics Workshop was conducted to identify families of applications using ROVER as the basic platform. Identification of the logistics and documentation packages is underway, with two additional units planned for delivery in FY 86.

REMOTELY OPERATED VEHICLE FOR EMPLACEMENT AND RECONNAISSANCE





- REMOTE CONTROLLED
- ELECTRIC POWERED
- EOD USE IN NEUTRALIZING UNEXPLODED ORDNANCE AND CONDUCTING RECONNAISSANCE
- CURRENTLY UNDERGOING TECHNICAL EVALUATION AND MISSION PROFILE TESTING

EXPLOSIVE ORDNANCE DISPOSAL

NAVEODTECHCEN has joint service responsibility for research in the area of Explosive Ordnance Disposal, and is working on several EOD projects of interest to the U.S. Army.

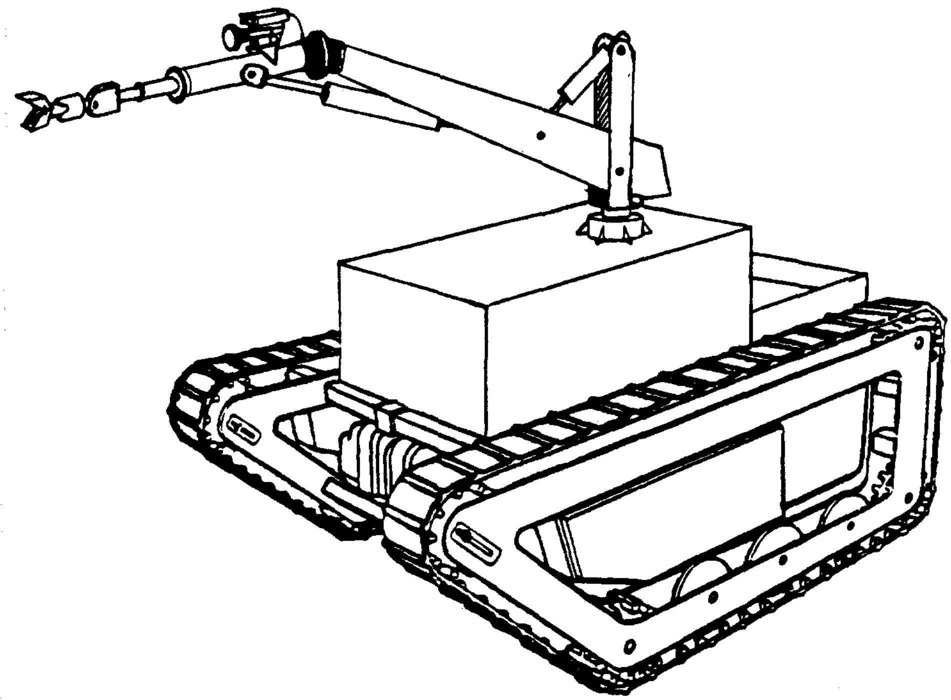
Semi-Autonomous Mobile System for Ordnance Neutralization

The Semi-Autonomous Mobile System for Ordnance Neutralization (SAMSON), formerly referred to as the Remote Ordnance Neutralization Device (RON-D), is one of these efforts. SAMSON, a FY 85 RDT&E new-start, is a remote-controlled mobile platform applying a technical approach similar to ROVER. SAMSON, however, incorporates enhanced sensory and manipulation capabilities not found in ROVER. A six degree-of-freedom manipulator will be used to operate onboard tool suites currently being identified and designed for EOD functions. SAMSON will be an electrically powered vehicle, and both wheeled and tracked versions are being investigated.

Remote Control Reconnaissance Monitor

The Remote Control Reconnaissance Monitor (ReCoRM) represents another joint service EOD project underway at NAVEODTECHCEN that is of interest to the U. S. Army. ReCoRM, a new start in FY 85, will emphasize transmission of sensor data. It is intended to be a highly portable, versatile and economic ground reconnaissance and monitoring vehicle with optional radio or cable control. ReCoRM will be a one-man portable, remote-control platform carrying a CCTV camera and other sensors appropriate to the task. It does not include a manipulator. A Request for Proposal (RFP) is currently in process for this effort.

SEMI-AUTONOMOUS MOBILE SYSTEM FOR ORDNANCE NEUTRALIZATION



- FY 85 RDT&E NEW START - A JOINT SERVICE PROJECT
- REMOTE CONTROL MOBILE PLATFORM:
  - TECHNICAL APPROACH SIMILAR TO ROVER
  - POSSESSES ENHANCED SENSOR AND MANIPULATION CAPABILITIES
  - SIX DEGREE-OF-FREEDOM MANIPULATOR
- ELECTRICALLY POWERED
- WHEELED AND TRACKED VERSIONS BEING INVESTIGATED

EXPLOSIVE ORDNANCE DISPOSAL

Remote Interface Concepts

NAVEODTECHCEN is developing various classes of tools and devices for use on remotely controlled vehicles. The Remote Interface Concept is an effort modifying existing information gathering systems into modular components for operation on platforms such as the Remotely Operated Vehicle for Emplacement and Reconnaissance (ROVER). The purpose is to improve safety and effectiveness of EOD operations by remotely deploying and operating intelligence gathering equipment.

Under a VSE Corporation subcontract to Engineering Technology, Inc., PDR-56, PDR-43E and PDR-27R radiation detection devices, an M18 chemical agent detection kit, and a MK 32 MOD 0 X-ray kit will be adapted for installation and remote operation on ROVER. The contractor's responsibilities are to collect and review pertinent technical data, including ROVER interface specifications, followed by design and fabrication of prototype modular accessories. (A modular accessory consists of the current hand-held manually-operated kit, and interface components required for adaptation of an unmodified kit to the vehicle.) Once adapted to the vehicle, the modular accessory must be capable of remote activation and remote detection of results.

The effort is scheduled for completion in FY 86 and includes support for hardware and system demonstrations. An internal EOD robotics workshop held at NAVEODTECHCEN identified the requirement for specific tool accessories, such as a high-powered, high-torque-producing rocket wrench, which will reduce the need to have EOD personnel in hazardous environments. (Rocket wrenches and other related tools are used to defuse, intentionally detonate, or otherwise disable ordnance.) When attached to a remotely-operated vehicle like ROVER, those tools allow the human operator to complete his EOD mission from a more secure location.

REMOTE INTERFACE CONCEPTS

- OBJECTIVE: TO DEVELOP MODULAR, REMOTELY OPERATED INTELLIGENCE GATHERING ACCESSORIES FOR ROVER BASED ON CURRENTLY FIELDED, HAND-HELD SYSTEMS

- PURPOSE: IMPROVE THE SAFETY AND EFFECTIVENESS OF EOD OPERATIONS

- SYSTEMS TO BE MODIFIED:
  - PDR-56, PDR-43E AND PDR-27R RADIATION DETECTION DEVICES
  - M18 CHEMICAL AGENT DETECTION KIT
  - MK 32 MOD 0 X-RAY KIT

- FY 85 EVENTS:
  - CONTRACT AWARDED
  - NAVEODTECHCEN ROBOTICS WORKSHOP

EXPLOSIVE ORDNANCE DISPOSAL

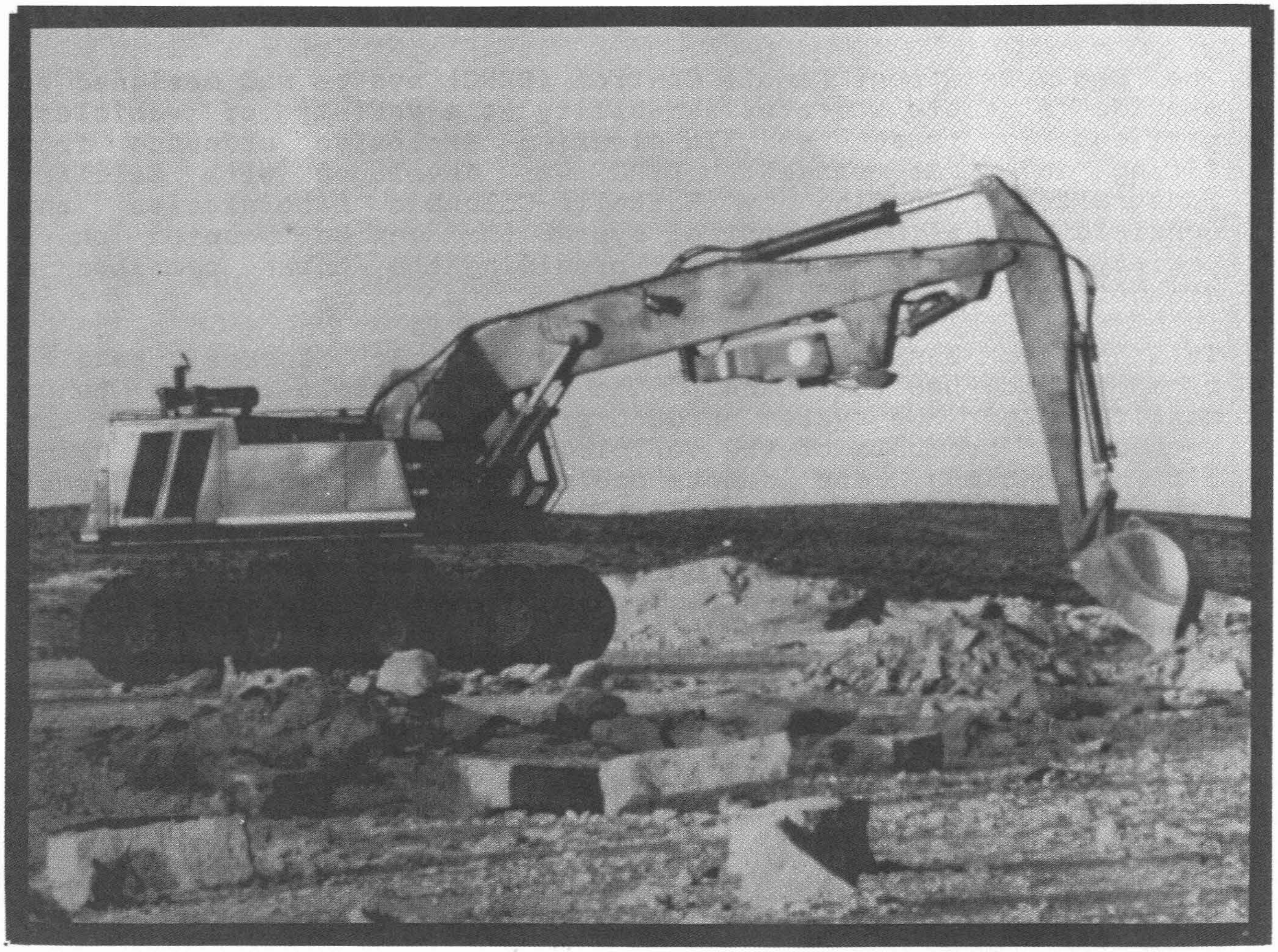
Remotely Operated Mobile Excavator

The Remotely Operated Mobile Excavator (ROME) was developed for NAVEODTECHCEN in 1983 by Foster Miller. Its primary purpose is to provide a rapid-deployment EOD capability to enhance air base survivability. ROME provides rapid removal of unexploded ordnance embedded in runways and supports Base recovery after attack. It is also useful in range clearance work, an increasingly important activity as former government test sites and gunnery ranges are reclaimed for other uses.

ROME, a 100,000 pound vehicle, uses a Standard Manufacturing Company undercarriage employing a Koehring Company excavator, with an extended boom and concrete breaker. In order to provide safe standoff distance, the operator is stationed in an armored personnel carrier, operating the system remotely through a tethered link with a take-up capability, at distances up to 70 meters. The operator is equipped with two video monitors and can select video from multiple cameras. Audio feedback is also available. During remote operation, ROME operates at 90% of its normal operating efficiency.

Informal evaluations of ROME are continuing under actual working conditions at China Lake and Eglin AFB. Follow-on efforts to provide system enhancements are currently being investigated.

REMOTELY OPERATED MOBILE EXCAVATOR



- PURPOSE:
  - RAPID REMOVAL OF UNEXPLODED ORDNANCE FROM RUNWAYS
  - RANGE CLEARANCE
  - RECOVERY OF SPECIAL TEST ITEMS
- CHARACTERISTICS:
  - HYDRAULICALLY ACTUATED
  - REMOTELY OPERATED FROM ARMORED PERSONNEL CARRIER
    - 70 METER STANDOFF
    - TWO VIDEO MONITORS, MULTIPLE CAMERAS
  - EMPLOYS EXTENDED BOOM AND CONCRETE BREAKER

EXPLOSIVE ORDNANCE DISPOSAL

Heavy Equipment Remote Control System

The Heavy Equipment Remote Control (HERC) system was designed to provide a remote operator capability to a variety of vehicles, particularly those used in clearing explosive ordnance from firing and test ranges. HERC was developed with Military Construction funding by Battelle-Columbus Laboratories and consists of a basic control system that can be mounted on a variety of heavy equipment, providing the human operator a standoff control capability.

This system has been tested on eight vehicle classes, ranging from a back-hoe to a tank. The control console can be hand-carried, and the system actuators are connected directly to the mechanical controls of the vehicle. Initially developed using 1980 technology, the remote operation achieves 50% of normal vehicle efficiency.

Product enhancements, including improved reliability, smaller system design, longer range and lower costs, are being investigated. A contract has been awarded to Griffiths International Corporation to install a HERC system on a government furnished bulldozer, the Caterpillar D7-F. No major technological risks are anticipated. The future effort will be directed toward fielding the system, with emphasis on unit cost reduction and standardizing components for use on a variety of heavy equipment.

HEAVY EQUIPMENT REMOTE CONTROL SYSTEM

HERC MOUNTED ON A HEAVY DUTY FORK LIFT, ONE OF MANY APPLICATIONS.

CHARACTERISTICS AND PERFORMANCE GOALS

- REMOTE OPERATOR CAPABILITY FOR VEHICLES OF OPPORTUNITY
- NO SPECIAL LOGISTICS OR TRAINING REQUIREMENTS
- CONTINUOUS OPERATING TIME NOT LESS THAN FOUR HOURS
- OPERATING RANGE NOT LESS THAN 6,000 FEET
- WEIGHT NOT MORE THAN 300 POUNDS

EXPLOSIVE ORDNANCE DISPOSAL

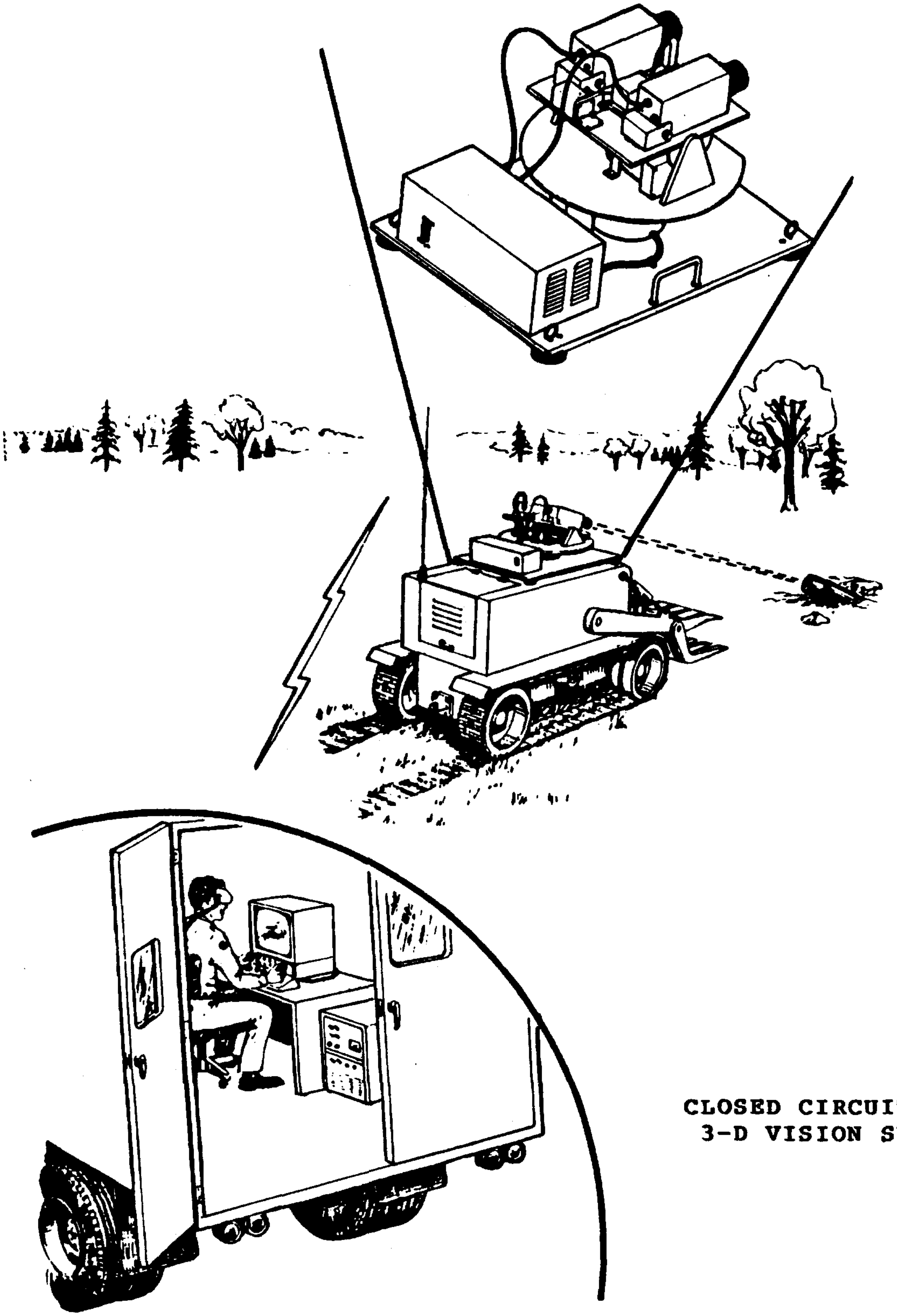
English Language Robot Communication

One of several areas of generic interest being pursued by NAVEODTECHCEN is the support of ongoing work at George Washington University to develop an English Language Robot Communication (ROBCOM) capability. This work is being performed by Professor Peter Bock, and is an outgrowth of an RDT&E 6.1 effort co-sponsored by the National Bureau of Standards. The objective, currently being pursued as a 6.2 project, is to develop a robotic system that is responsive to a high level English control language. The concept of the English language hierarchy was demonstrated under the 6.1 effort. The initial software implementation has been completed and the system is being integrated on a recently fabricated microprocessor-based mobile robot. Using a keyboard, commands are at present transmitted via cable, although integration of an RF link is underway.

3-D Vision--Human Operators

NAVEODTECHCEN has a contract with Honeywell to develop an enhanced vision system for remote operators of semi-autonomous systems. This project concentrates on developing a controlled-parallax capability by using a closed-circuit, dual-camera 3-D vision system. Video signals are transmitted to the remote location via fiber-optic or RF link. The stereo images are presented on a single TV monitor, which the operator views with specially configured goggles that effectively redirect the left and right camera images to the operator's eyes in such a fashion as to provide a three dimensional "telepresence" effect. Applications include adaptation of existing remote control vehicles to telepresence systems, to take advantage of the depth perception provided by the stereo cameras. The prototype has been received from Honeywell and is currently undergoing evaluation.

3-D VISION--HUMAN OPERATORS



CLOSED CIRCUIT DUAL 3-D VISION SYSTEM

EXPLOSIVE ORDNANCE DISPOSAL

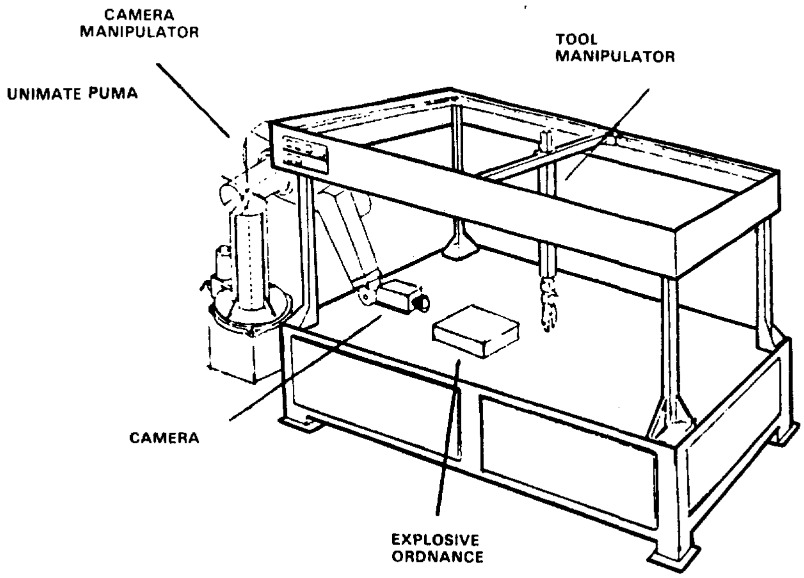
Guided Robotic Disassembly System

The Guided Robotic Disassembly System (GRIDS) for Explosive Ordnance Disposal (EOD) is a highly accurate, interactive, robotic workcell designed to perform remote disassembly functions in support of EOD operations. The current system, developed at the University of Texas at Austin, is implemented on a static laboratory platform and consists of a pair of robot manipulators, a single-camera 3D vision system, an array of collision avoidance and guidance sensors, an interactive graphics workstation and a hierarchical controller. These components are effectively integrated in this man-in-the-loop workcell to achieve positional accuracies of one-thousandth of an inch in near-real-time.

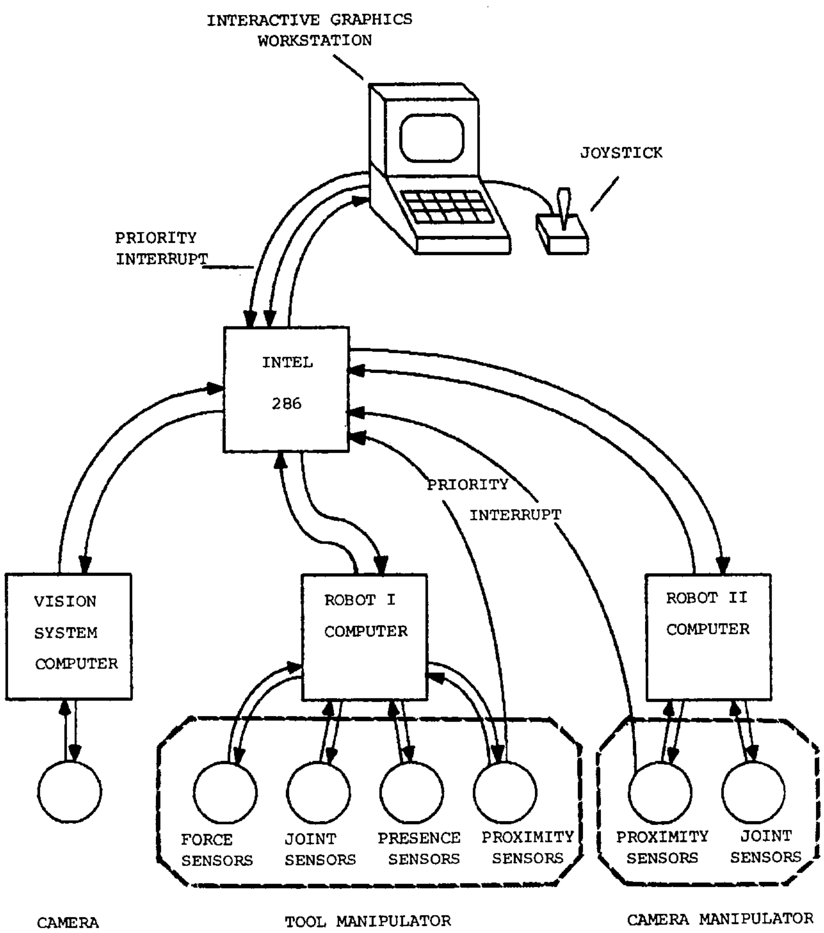
The guided approach used in GRIDS provides the EOD community with advanced capabilities not found in previously employed teleoperated systems. The construction of three-dimensional models using computer vision gives the operator more detailed information in a form easier to visualize than the usual single video monitor. Coupled with the interactive graphics techniques available to manipulate the model for inspection, GRIDS provides information difficult to obtain otherwise.

GRIDS is a self-calibrating system. Using visual images of known objects such as a tool, it is possible to determine and correct errors due to inaccuracies in the manipulators themselves. In addition, automatic trajectory planning relieves the operator of the tedium of positioning the manipulator with a teach pendant. Finally, the sensor capabilities, error recovery procedures and hierarchical control structure of GRIDS ensure that no unplanned impact is made with the ordnance, and planned contacts will only exert forces determined safe by the operator.

GUIDED ROBOTIC DISASSEMBLY SYSTEM



GRIDS ROBOTIC WORKCELL FOR EOD DISASSEMBLY FUNCTIONS



HARDWARE SCHEMATIC ILLUSTRATING COMMUNICATION BETWEEN COMPONENTS

EXPLOSIVE ORDNANCE DISPOSAL

Surface/Subsurface Clearance Vehicle

Large tracts of land used as ordnance impact areas or test ranges have over the years become contaminated with unexploded munitions and debris, the quantity and condition of which is largely unknown. In order to render these tracts safe for redevelopment or continued use, they must be cleared of all unsafe ordnance. Therefore, range clearance equipment such as the Surface/Subsurface Clearance Vehicle (SSCV) is being developed to mechanically remove ordnance and related debris from the soil. This device will be capable of making multiple passes over an area, digging to a predetermined soil depth. The speed at which this is accomplished is dependent upon the soil properties, degree of contamination and amount of debris. Items ranging in size from 39mm to 155mm in diameter and up to 1.5 meters long will be separated from the soil. The operation is remotely supervised, using both radio and video equipment, in order to conduct removal clearance operations at a safe standoff distance. Following earlier prototype demonstrations, the FY 85 effort has concentrated on the development of design requirements for a ruggedized system.

Borehole Location/Detection System

NAVEODTECHCEN is investigating the Borehole Location/Detection System, a joint service application funded by the U.S. Army Corps of Engineers, as a low-cost technique to effectively locate buried ordnance. The detection of buried ordnance is complicated by the extreme sensitivity of electronic measuring systems to the distance between the sensor and target. Often, the signal-to-noise ratio diminishes to the point where the system is ineffective. The objective is to develop a technique which uses existing drilling, sensor and information processing technology effectively to overcome this problem. Because of the limitations of current surface operated systems used for the location of buried ordnance, it is necessary to drill to position the sensor in proximity to the probable location of unexploded ordnance. During FY 85, a feasibility study was conducted to address sensor design characteristics. Geo-Centers, Inc. is currently assessing sensor capabilities and developing field tests to be conducted during FY 86.

SURFACE/SUBSURFACE CLEARANCE VEHICLE

- OBJECTIVE: TO MECHANICALLY REMOVE UNEXPLODED ORDNANCE AND RELATED DEBRIS FROM ORDNANCE IMPACT AREAS
- REQUIREMENTS:
  - DIG TO A PREDETERMINED SOIL DEPTH
  - MAKE MULTIPLE PASSES AT REASONABLE SPEED
  - SEPARATE AND COLLECT ITEMS FROM SOIL
  - PROVIDE 3.5 METER CUTTING SWATH
  - INTERFACE WITH REMOTE RADIO AND VIDEO MONITORING EQUIPMENT

BOREHOLE LOCATION/DETECTION SYSTEM

- OBJECTIVE: DEVELOP AN EFFECTIVE AUTOMATIC SYSTEM FOR LOCATING BURIED ORDNANCE, USING EXISTING DRILLING, SENSOR AND INFORMATION PROCESSING TECHNOLOGY
- DETECTION OF BURIED ORDNANCE COMPLICATED BY:
  - SENSITIVITY OF ELECTRONIC MEASURING SYSTEM TO DISTANCE BETWEEN SENSOR AND TARGET
  - POOR SIGNAL TO NOISE RATIO
- SOLUTION: DRILL TO POSITION SENSOR IN PROXIMITY TO UNEXPLODED ORDNANCE
- GEO-CENTER, INC. ASSESSING SENSOR CAPABILITIES AND DEVELOPING FY 86 FIELD TESTS

EXPLOSIVE ORDNANCE DISPOSAL UNDERWATER SYSTEMS

Advanced Development Remotely Operated Vehicle

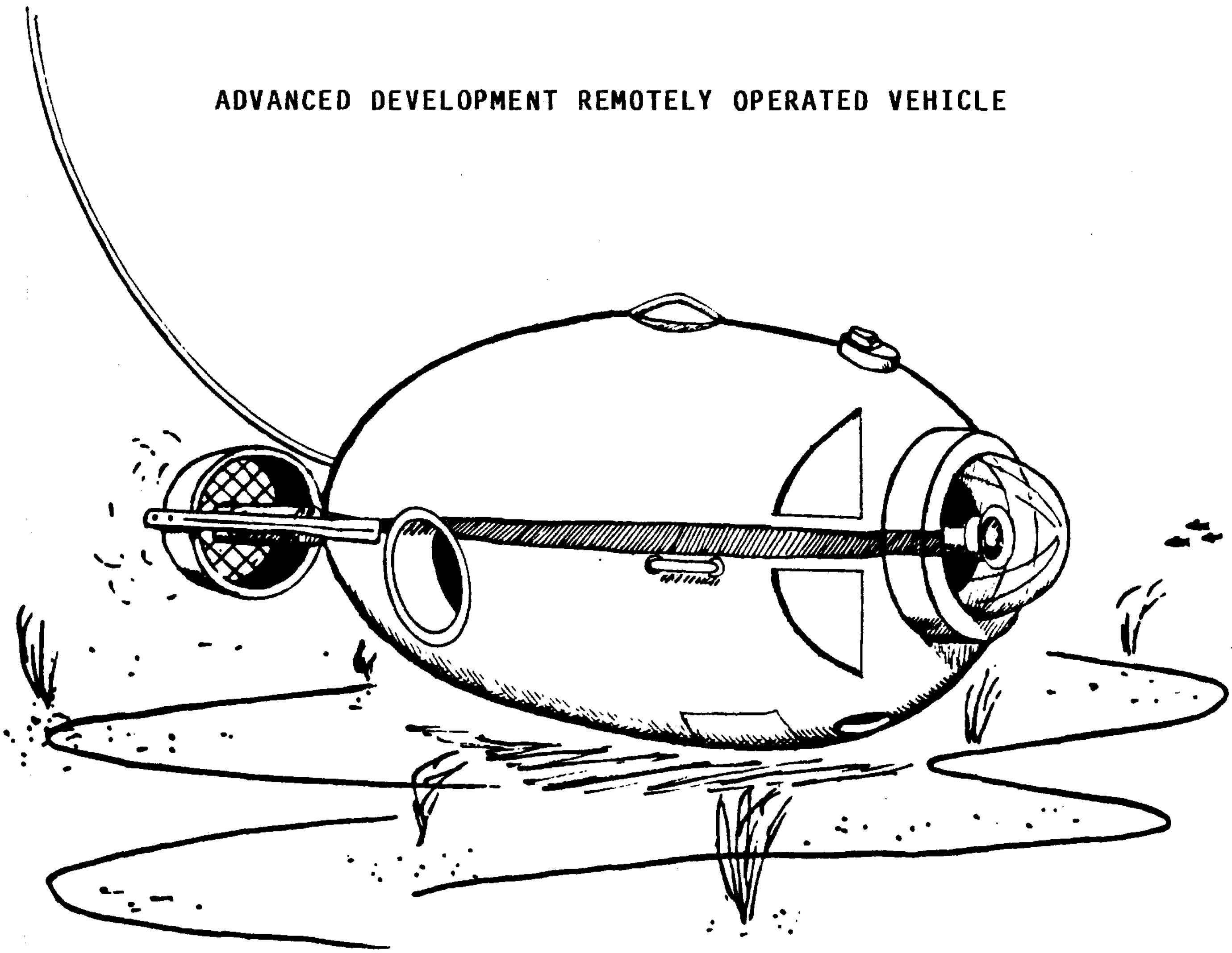
The Advanced Development Remotely Operated Vehicle (ADROV) is a Demonstration/Validation prototype designed to locate, inspect, and mark specific targets (primarily unexploded ordnance) on the sea floor. It will operate in two knots of current to depths of 328 feet while standing 300 feet off from the support platform. The 200 pound vehicle is controlled from the surface through an 800 foot negatively-bouyant umbilical. ADROV is equipped with four electro-hydraulic thrusters. It carries a black and white video camera system, various sensors and associated electronics, and features a high definition sonar color display.

The prototype was delivered by the manufacturer, Hydro Products, Inc. to NAVSEA in July 1985. Developmental testing was conducted from August 1985 - April 1986.

The DT I objective was to assess the ability of the vehicle to locate, inspect, and mark (with a payload) a particular target. The testing was divided into two phases, with the first phase conducted on the West Coast in an ideal environment. The second phase was conducted in the Patuxent River near Solomons Island, where poor water conditions simulated those found in most harbors.

The basic objectives of the system test and evaluation were achieved. The EOD personnel mastered system operation, developed control skills, and demonstrated an ability to adapt quickly as conditions deteriorated. The rigorous evaluation encompassed a total of 54 operational hours and included over 40 dives, more than half of which simulated actual EOD missions. The vehicle has operated to depths of 250 feet at speeds estimated at 3 knots, and demonstrated a capability of "flying" at over 4 knots, diving at 1 meter per second, locating mine-like contacts to a range of 50 meters, and inspecting and marking targets, all while carrying a payload.

ADVANCED DEVELOPMENT REMOTELY OPERATED VEHICLE



- DESIGNED TO LOCATE, INSPECT, AND MARK SPECIFIC TARGETS
- CONTROLLED FROM SURFACE PLATFORM:
  - USES AN 800 FOOT UMBILICAL
  - ALLOWS 300 FOOT STAND-OFF IN 2 KNOT CURRENT
  - OPERATES TO DEPTHS OF 328 FEET
- EQUIPMENT:
  - FOUR ELECTRO-HYDRAULIC THRUSTERS
  - BLACK AND WHITE VIDEO CAMERA SYSTEM
  - HIGH DEFINITION SONAR COLOR DISPLAY
  - VARIOUS SENSORS
- BASIC TEST AND EVALUATION OBJECTIVES ACHIEVED

EXPLOSIVE ORDNANCE DISPOSAL UNDERWATER SYSTEMS

PLUTO

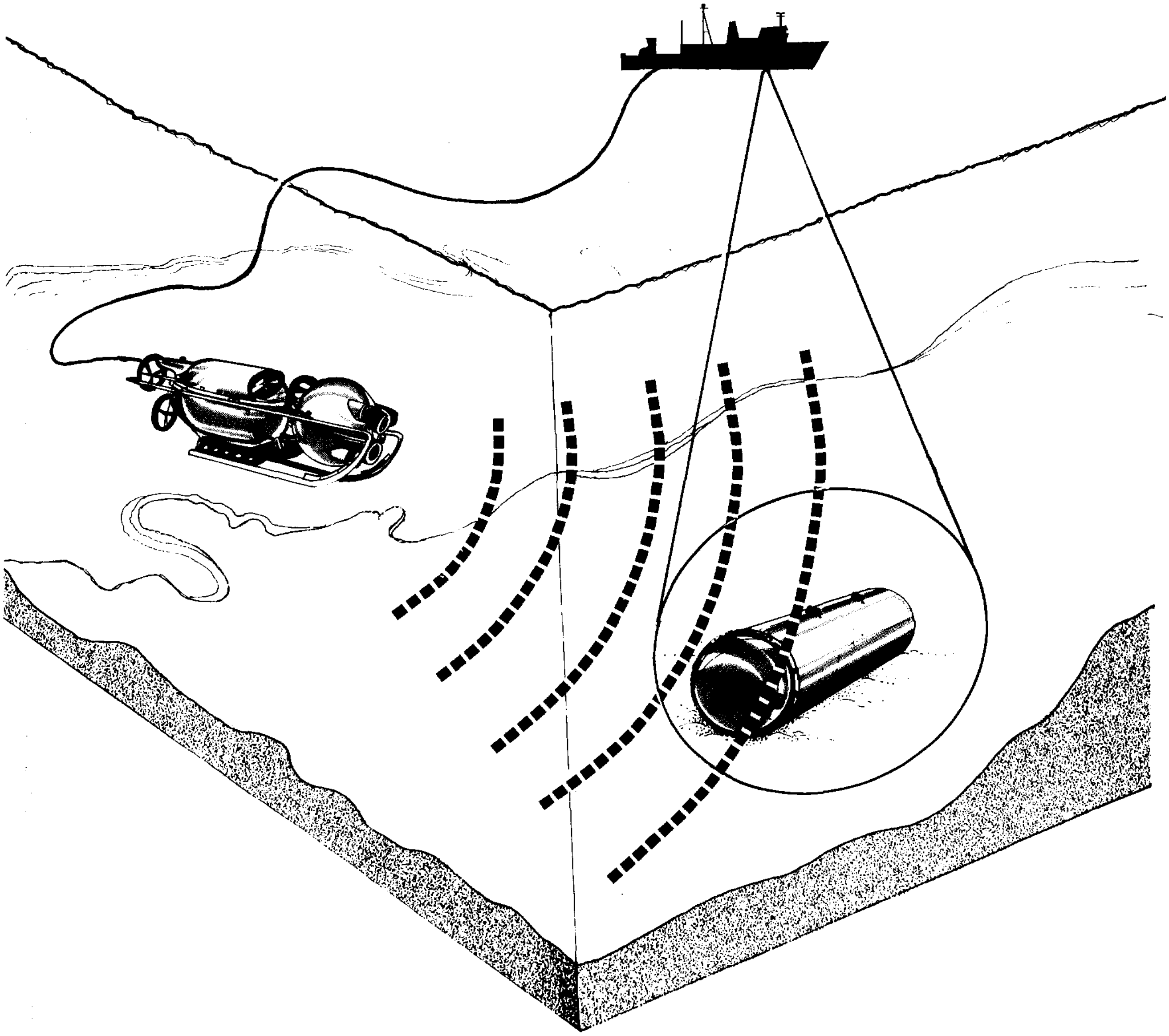
As part of the NAVSEA Foreign Weapons Evaluation effort, NAVEODTECHCEN is conducting an appraisal of the PLUTO underwater vehicle. This tethered vehicle is capable of operating to depths of 1000 feet. It is equipped with sonar and a video camera system. PLUTO is controlled by a single coaxial cable, has an onboard power source, and is unique in that it is the only ROV in its class that is battery powered. While PLUTO is operating at speeds up to 1 knot, the batteries can be trickle-charged through the cable, and maintained at full capacity.

The PLUTO system was delivered to NAVEODTECHCEN on 10 September 1985. PLUTO has been subjected to extensive testing and evaluation.

Phase I of the PLUTO system test and evaluation was planned to take place in the Solomon Annex area of the Patuxent River Naval Air Test Center in order to use the facilities that were available for the continuing ADROV testing.

The test objectives laid down in the PLUTO test plan are summarized below:

1. Train Navy personnel in the maintenance, deployment and recovery of the PLUTO system.
2. Establish minimal Crew Operating Platform requirements for PLUTO operations.
3. Ascertain technical and operational characteristics in a variety of EOD/MCM scenarios.
4. Provide comparative data with the ADROV system.
5. Determine reliability, maintainability, and supportability of the system.



NAVEODTECHCEN IS CONDUCTING AN APPRAISAL OF PLUTO, A TETHERED REMOTELY OPERATED VEHICLE CAPABLE OF OPERATING TO DEPTHS OF 1000 FEET. PLUTO, BATTERY POWERED AND EQUIPPED WITH A SONAR AND VIDEO CAMERA, IS A PORTABLE TOOL FOR APPLICATIONS IN THE EOD/MCM COMMUNITY.

NAVY SALVAGE OPERATIONS

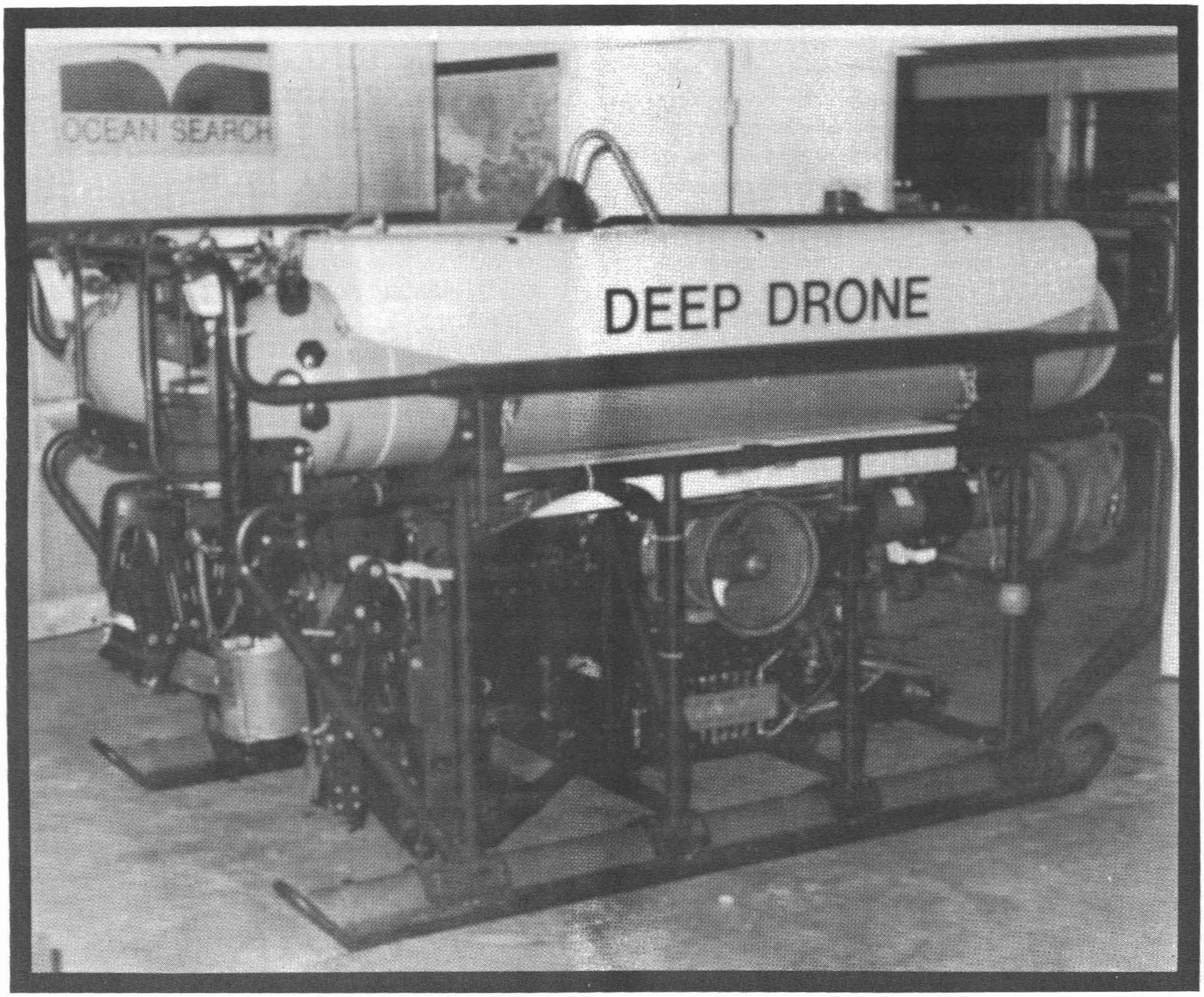
Deep Drone is an operational teleoperated tethered vehicle equipped with both a seven degree-of-freedom and a five degree-of-freedom manipulator. It is used to perform deep ocean salvage operations. This system is capable of operating at depths of 6000 feet and at speeds up to 2 knots, incorporating both a black-and-white and color TV camera, a 360-degree search sonar, and a bottom navigation system. This project is under the technical direction of SEA 00C (Tom Salmon), and is constantly being updated to incorporate proven advances in robotic technology.

OTHER UNDERWATER PROJECTS

For the past several years, SEA 05R (John Freund) has conducted an active program in underwater research in teleoperated and robotic systems at NOSC, where an Advanced Tethered Vehicle is being developed for underwater work tasks. The vehicle is electrically driven through a tether and can be operated from most vessels. It is equipped with sonar and video cameras, navigation sensors, and a work package with tools and manipulators. In the teleoperated mode the vehicle communicates with the operator via a fiberoptic link, receiving commands during the retrace portion of the video signal being sent to the surface monitor.

An Undersea Search Vehicle is also being developed by NOSC, capable of conducting rapid underwater searches from vessels in the open ocean in an untethered mode, at great depths and high speed. The system consists of a search vehicle, a communications relay buoy and shipboard support equipment. The search vehicle carries high-resolution sonar and video equipment capable of providing freeze-frame pictures to the controlling vessel. The data, relayed to the ship via a towed hydrophone, is displayed to two system operators aboard the ship, one controlling the search vehicle and the other interpreting data.

The Deep Submergence Systems Program (PMS-395) is developing performance specifications for a master/slave manipulator arm system for the DSV 3 vehicle. The manipulator outboard arm (slave) is to be designed to be completely compensated by the vehicle hydraulic system, allowing operation to a depth of 20,000 feet. The slave will be controlled with a bilateral replica controller (master) which will be designed for use in the one atmosphere, closed environment of the DSV 3 personnel sphere. The master will use electrical control signals (inboard) which shall interface with the hydraulic power (outboard) to control the motion and position of the slave.



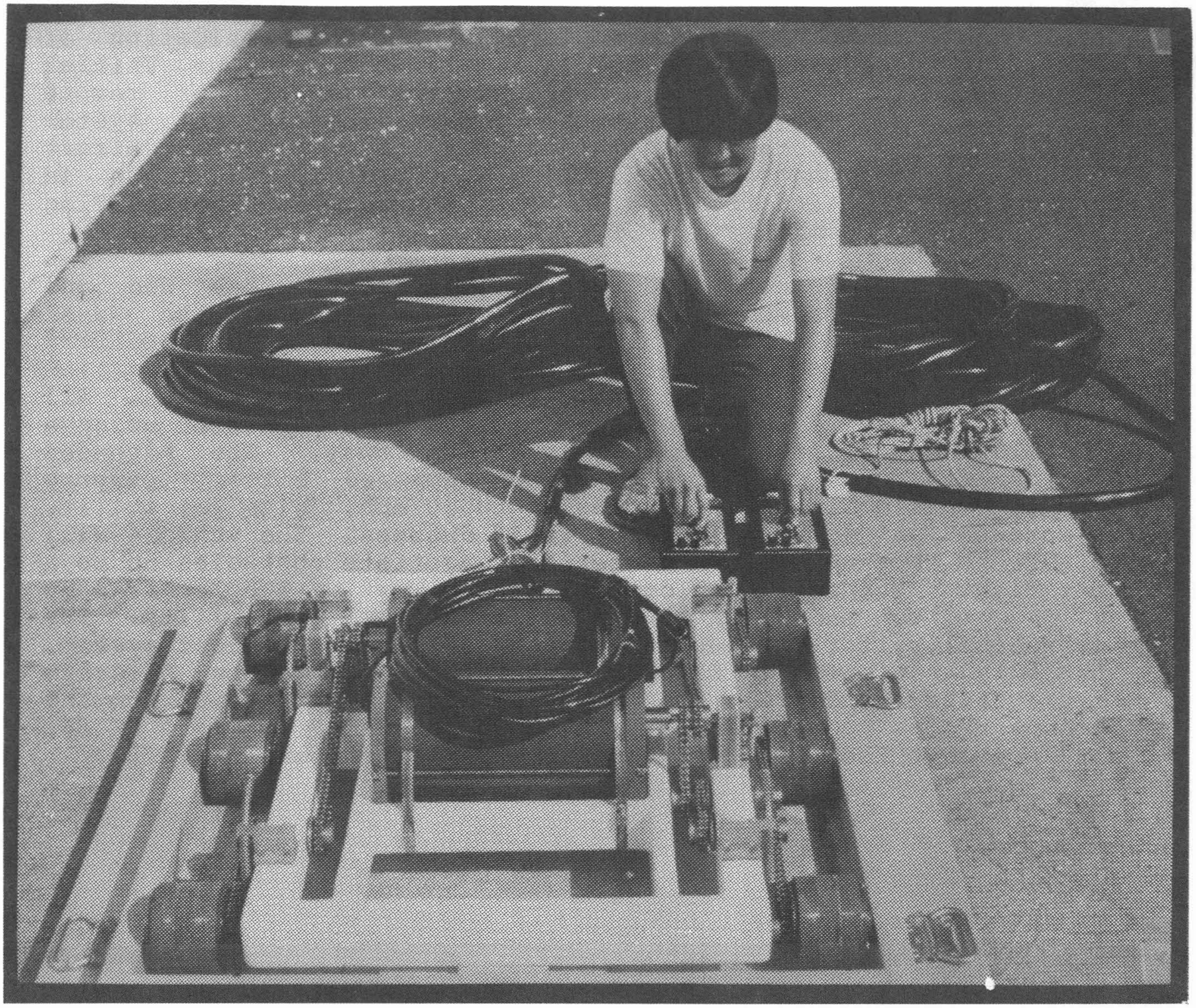
OTHER NAVSEA UNDERWATER PROJECTS:

- ADVANCED TETHERED VEHICLE
- UNDERSEA SEARCH VEHICLE
- DSV 3 MANIPULATOR ARM
- NR-1 MANIPULATOR ARM

ROBOTIC HULL INSPECTION SYSTEM

NAVSEA efforts to apply robotics technology to the performance of maintenance and repair work included plans for the development of a prototype hull inspection system. The project was managed by Fred Saxton (SEA 05R12B) under the technical direction of Dr. Ross L. Pepper of the Naval Ocean Systems Center in Hawaii. Due to funding constraints the effort was not pursued during FY 85. The remotely operated robotic hull inspection robot was designed for underwater inspection of a ship hull, propeller and shaft. The project included development of a tethered mobile platform that can traverse the hull, a navigational capability for maintaining orientation, and a video capability.

ROBOTIC HULL INSPECTION SYSTEM



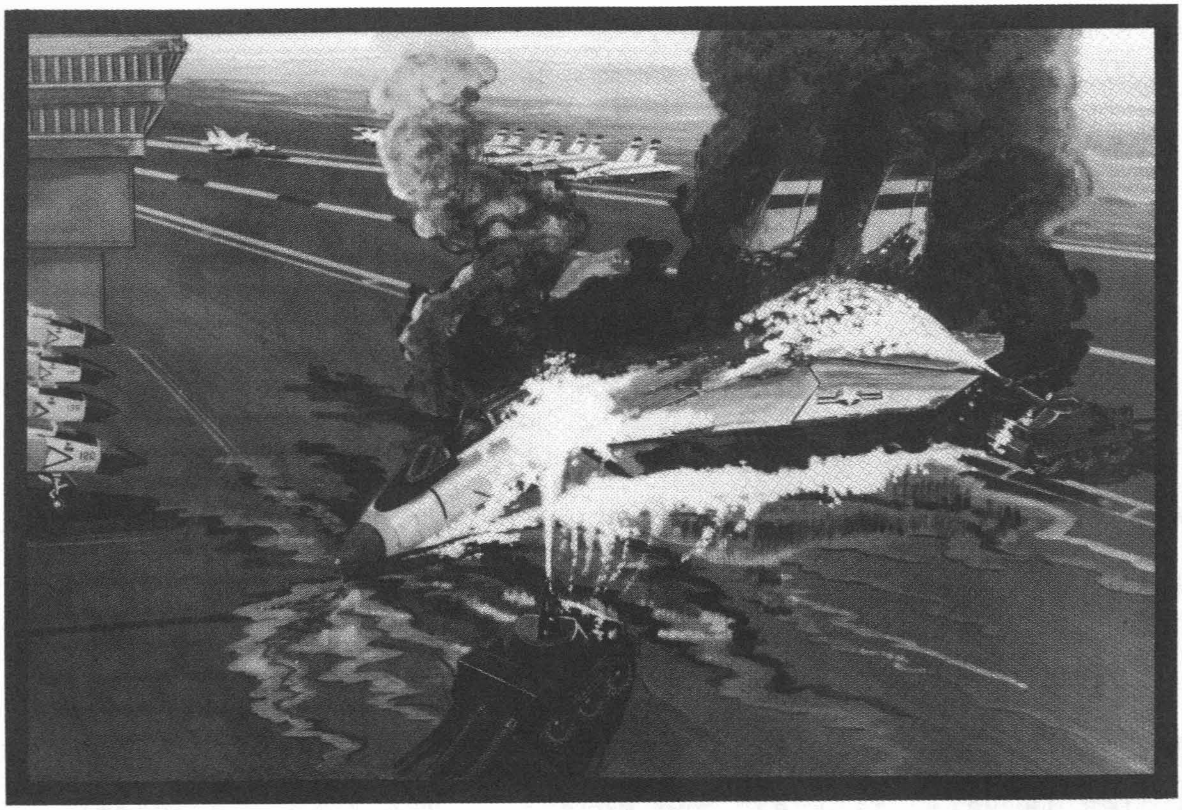
- PROTOTYPE HULL INSPECTION SYSTEM
- UNDERWATER INSPECTION OF HULL, PROPELLER AND SHAFT
- TETHERED PLATFORM WITH NAVIGATION AND VIDEO CAPABILITY

REMOTE CONTROL FIREFIGHTING PLATFORM

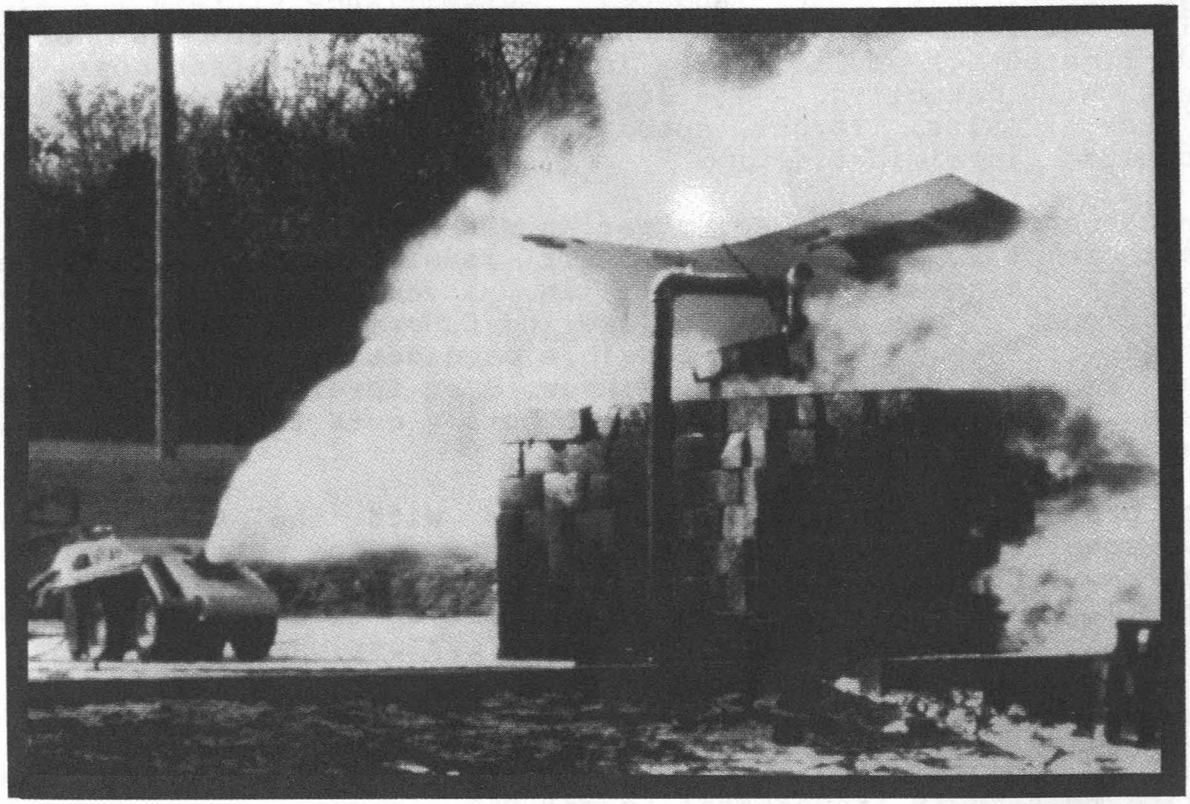
Considerable emphasis has been placed upon the investigation of robotic systems designed for use in hazardous operations. Initial efforts in this area have emphasized teleoperated or remote controlled devices, with the operator providing all the system intelligence. In the firefighting area the initial Navy effort is the Remote Control Firefighting Platform (RCFP), begun in response to direction from the Aircraft Carrier Firefighting Flag Level Steering Committee (CVFF/FLSC).

The RCFP is a teleoperated hose delivery system designed and built by a development team headed by Mary Lacey at the Naval Surface Weapons Center. The base platform is a modified hydrostatic front-end loader powered by an internal combustion engine, equipped with trainable remote directed nozzles. All vehicle and nozzle functions are directed by an operator using a handheld control station up to 500 feet away. The Advanced Development RCFP is designed as an unmanned battery powered tracked vehicle capable of speeds up to 10 mph, with the ability to maneuver on decks inclined up to 15 degrees. The vehicle will be able to turn on its own center and negotiate obstacles up to a foot high. The umbilical control system may be supplemented by an RF link, and will have a built-in test capability. The responsibility for development of this reliable, low-cost system, initially assigned to NAVSEA, was turned over to the Aircraft Firefighting and Rescue Branch of the Naval Air Systems Command during FY 85. Operational testing is scheduled for late FY 86, with possible Fleet introduction as early as the end of FY 87.

REMOTE CONTROL FIREFIGHTING PLATFORM



ARTIST CONCEPT OF REMOTE CONTROL FIREFIGHTING PLATFORM



A PROTOTYPE TELEOPERATED FIREFIGHTING SYSTEM UNDERGOING PRELIMINARY TESTING BY THE ROBOTICS RESEARCH AND DEVELOPMENT LABORATORY AT NSWC

WATERSIDE SECURITY SYSTEM PROGRAM

In FY 85 Congress mandated a demonstration of commercially available equipment which could be used to enhance the security of DoD waterfront areas. Due to the Air Forces' responsibility for Base and Installation Security Systems, initial management for the demonstration was assigned to the Air Force who requested Naval Sea Systems Command (NAVSEA) to provide the Program Manager. The Director, Nuclear Weapons and Munitions Security Division, SEA 643, formally accepted this function in March 1985. Five million dollars was initially programmed for the test. A Technical Steering Committee formed under SEA 643, supports the Waterside Security System (WSS) demonstration and includes naval laboratories and private research organizations.

The purpose of the test is to demonstrate existing electronic underwater and surface security systems, in an attempt to reduce physical damage, intelligence collection, and unintentional trespass. The threats to be addressed are: (1) fast boat, (2) sneak boat, (3) surface swimmers, (4) underwater swimmers, and (5) underwater vehicles.

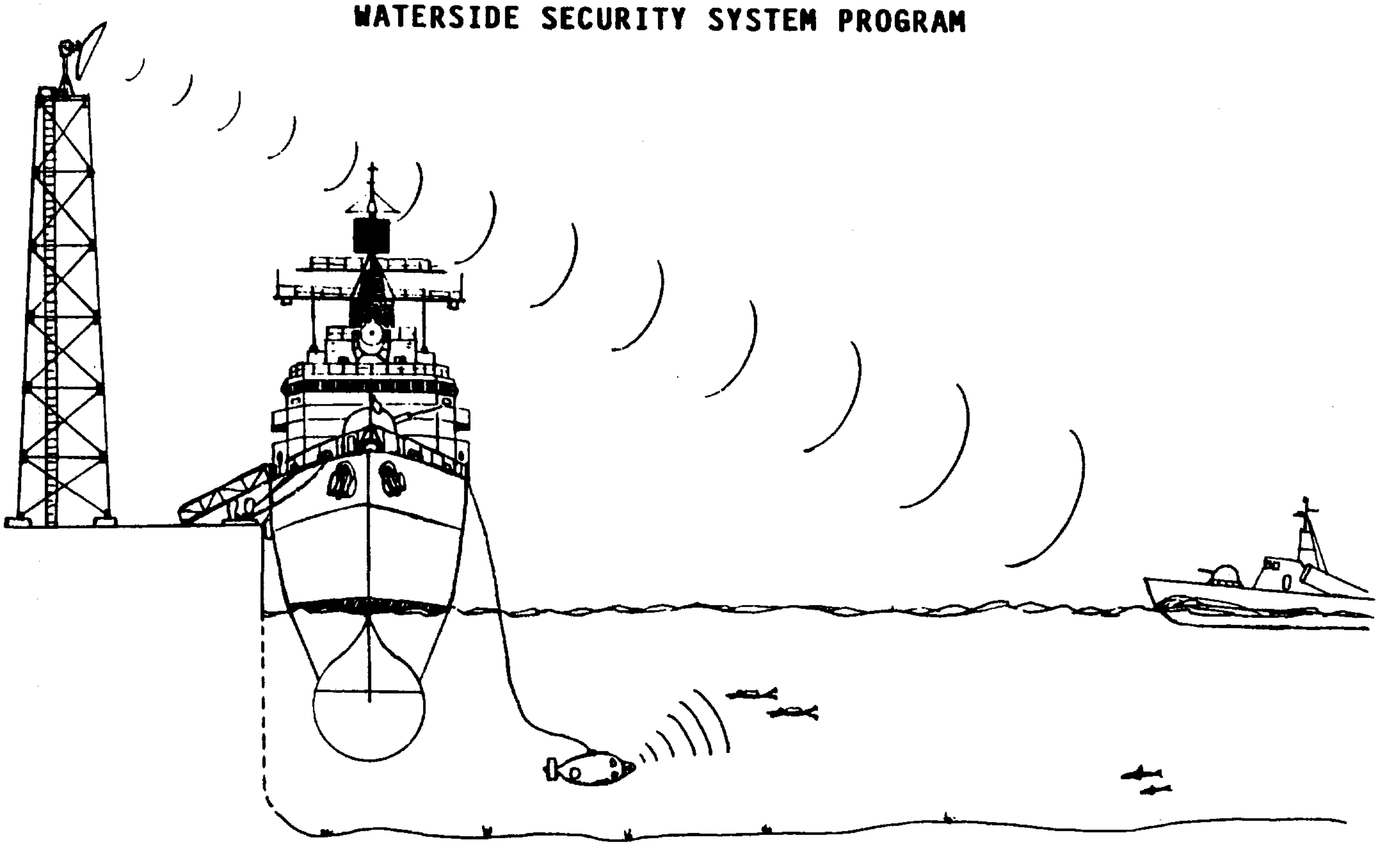
Components under consideration include imaging devices, deployed at fixed shore positions and mounted on remotely operated vehicles (ROVs); radars; and sonars. The sonar equipment is designed to detect swimmers, underwater vehicles, and surface craft. Imaging devices, including infrared, reduced- and low-light level television, and CCTV surveillance systems are also being evaluated as assessment devices. Radar is being investigated for applicability in surface swimmer, fast boat, and sneak boat detection. The evaluations consider parameters such as target size, target speed, structure discrimination and shoreline discrimination.

One segment of the WSS Demonstration was to evaluate commercially available ROVs to determine their feasibility as underwater platform assessment devices in investigating potential intrusions. Naval Civil Engineering Laboratory, Port Heuneme, was directed to investigate possible candidates. NCEL reviewed four vehicles to date: the Minnow, Sea Rover, Hysub 10, and Hysub 30. Unfortunately due to budgetary cuts the ROV phase was canceled.

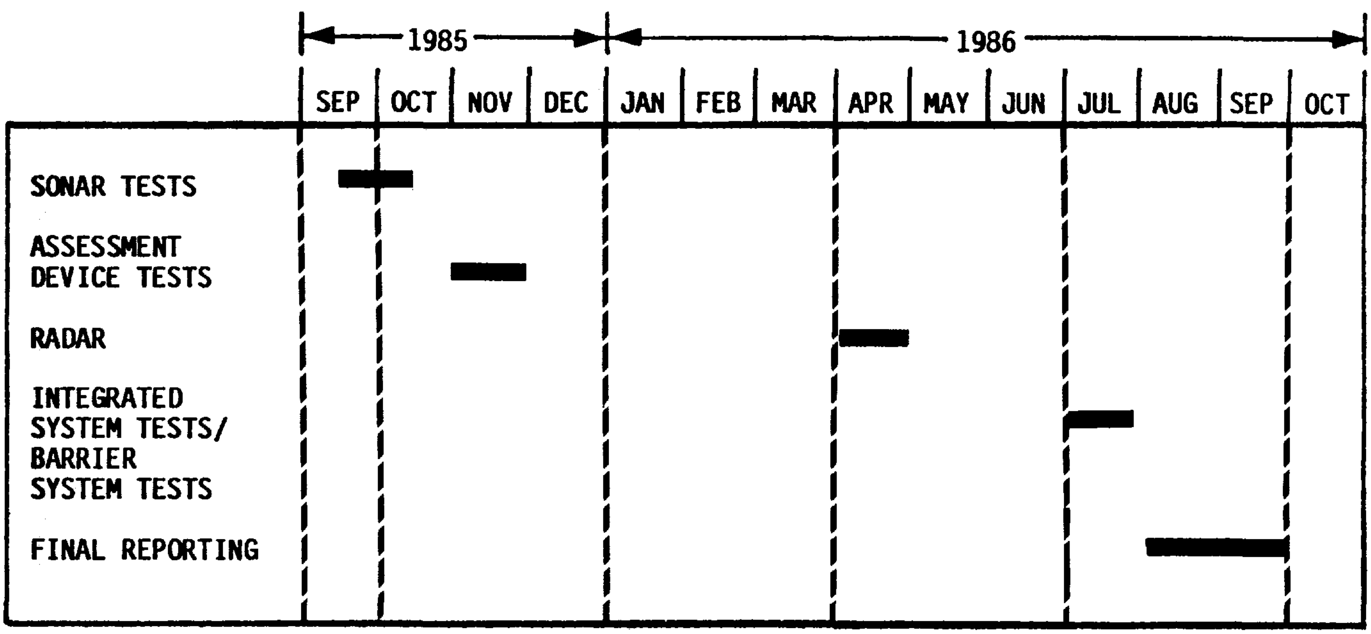
The project testing schedule begins with the testing and assessment of the specific sensor systems. The total integrated systems test will be conducted during June 1986 and will assess performance of the integrated system made up of candidate devices emerging from the individual component evaluations.

It should be noted that in May 1985, the responsibility for waterside security was formally transferred from the Air Force to the Navy. The investigation of ROV applications will be addressed during this newly transferred formal R&D program.

WATERSIDE SECURITY SYSTEM PROGRAM



WSS DEMONSTRATION PROJECT SCHEDULE



ROBOTICS FOR PHYSICAL SECURITY

The Nuclear Security Research and Development Division of the Defense Nuclear Agency is authorized to expend Exploratory Development (6.2) funds for security systems development. The Physical Security Equipment Action Group, a joint service organization chaired by a representative of the Under Secretary of Defense for Research and Engineering, in response to requests from the Army, Navy, and Air Force, authorized the Defense Nuclear Agency (DNA) to examine the possible use of robotics in the security field.

Doug Cavileer of OP-09N and John Lally of SEA 6432 represent the Navy in providing technical review and oversight to this project from the physical security perspective; NSWC Code R-402 (Russ Werneth), NOSC Code 442 (Scott Harmon), and SEA 90G provide supporting technical expertise in robotics. Improved security, reduced costs, and reduction of required manpower are all believed to be possible through application of emerging robotics technologies to physical security needs.

Meridian Corporation conducted the Phase I feasibility study under contract to DNA, from June 1984 through February 1985. The Final Report, DNA-TR-84-422, titled <u>An Evaluation of Robotics for Physical Security</u>, provides a background of current physical security practices at weapons storage sites, both in the United States and abroad. The objective of the study was to assess the state-of-the-art of robotics technologies as they may potentially apply to the physical security of nuclear weapons at fixed land-based storage sites in order to enhance security effectiveness, reduce manpower costs, and modernize security practices. The report concluded:

1. Robotic technologies have significant potential for security improvement, particularly in manpower reduction.

2. Current and projected available robotic technologies appear highly applicable to nuclear weapons physical security, especially for response, detection, and assessments.

3. Physical security functions for which robotic technologies appear most applicable are also those that offer the greatest opportunity for improvement.

ROBOTICS FOR PHYSICAL SECURITY

- DEFENSE NUCLEAR AGENCY IS INVESTIGATING APPLICATION OF ROBOTICS TO SECURITY SYSTEMS
  - AUTHORIZED BY THE PHYSICAL SECURITY EQUIPMENT ACTION GROUP--USDRE
  - EXPLORATORY DEVELOPMENT UNDERWAY

- NAVY TECHNICAL REVIEW AND OVERSIGHT:
  - PHYSICAL SECURITY
    - OP-09N
    - SEA 6432
  - ROBOTICS
    - SEA 90G
    - NSWC R-402
    - NOSC 442

- OBJECTIVES:
  - IMPROVED SECURITY
  - REDUCED COSTS
  - REDUCTION OF REQUIRED MANPOWER

- PHASE I FEASIBILITY STUDY:
  - JUNE 1984 TO FEBRUARY 1985
  - CURRENT AND PROJECTED ROBOTIC TECHNOLOGIES APPEAR APPLICABLE TO NUCLEAR WEAPONS PHYSICAL SECURITY
  - POTENTIAL APPLICATIONS SPAN WIDE RANGE OF TECHNICAL DIFFICULTY, RISK, AND PAYOFF
  - SIGNIFICANT ADVANCES REQUIRED IN SOME ROBOTIC TECHNOLOGIES

- PHASE II CONCEPT DEFINITION:
  - INITIATED AUGUST 1985
  - CONTRACT AWARDS TO:
    - MERIDIAN CORPORATION
    - ODETICS, INC.
    - SCIENCE APPLICATIONS INTERNATIONAL CORPORATION

ROBOTICS FOR PHYSICAL SECURITY (Continued)

4. Potential robotic technology applications span a wide range of technical difficulty, risk, and payoff:

   - Response function: Potential for a large payoff, using technology beyond the state-of-the-art, in augmenting response functions.

   - Detection/Assessment Functions: Potential for substantial near term payoff with near state-of-the-art technology in the area of augmenting detection and assessment.

5. Significant advances in some supporting technologies are required in order to realize the full potential for improving nuclear weapons security:

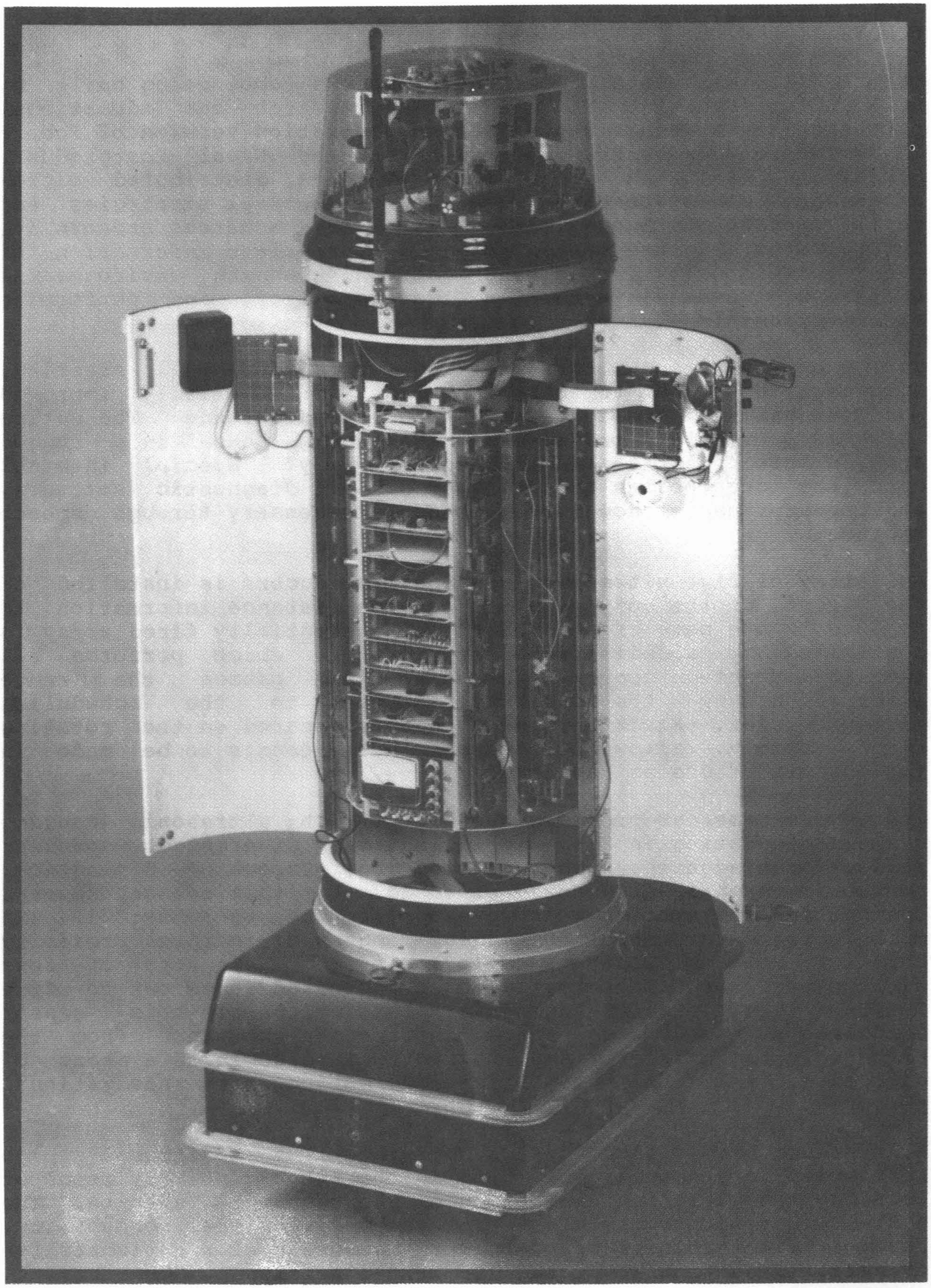
   - AI: Expert Systems, Intelligent Planners, Natural Language Interfaces

   - Sensors: Sensor Fusion, Vision, Intrusion Detection, Millimeter Radar

   - Mobility: Collision Avoidance, Navigation, Telepresence, Teleoperation

The report is available to government agencies and their contractors through the Defense Technical Information Center.

Phase II, the follow-on Concept Definition Phase of the Robotics for Physical Security Program, was initiated in August 1985 with the award of independent contracts to Meridian Corporation, Odetics, Inc., and Science Applications International Corporation. The objective is to provide the Services with as many concepts as possible, encourage competition, and ensure a valid set of options for design and construction of prototypes in Phase III.



ROBART II, A PROTOTYPE SENTRY ROBOT USED FOR RESEARCH AND EVALUATION (SEE PAGE 112)

ROBART II

Robart II is a battery powered autonomous robot being built by LCDR Bart Everett of NAVSEA for research and educational purposes, as a much improved second generation version of Robart I, a prototype sentry robot built at the Naval Postgraduate School in 1981. An architecture of nine distributed microprocessors makes possible more advanced control strategies and vastly improved data acquisition capability. Numerous sensors are incorporated into the system to yield appropriate information for use in collision avoidance, navigational planning, environmental awareness, assessing terrain traversability, and performing security functions.

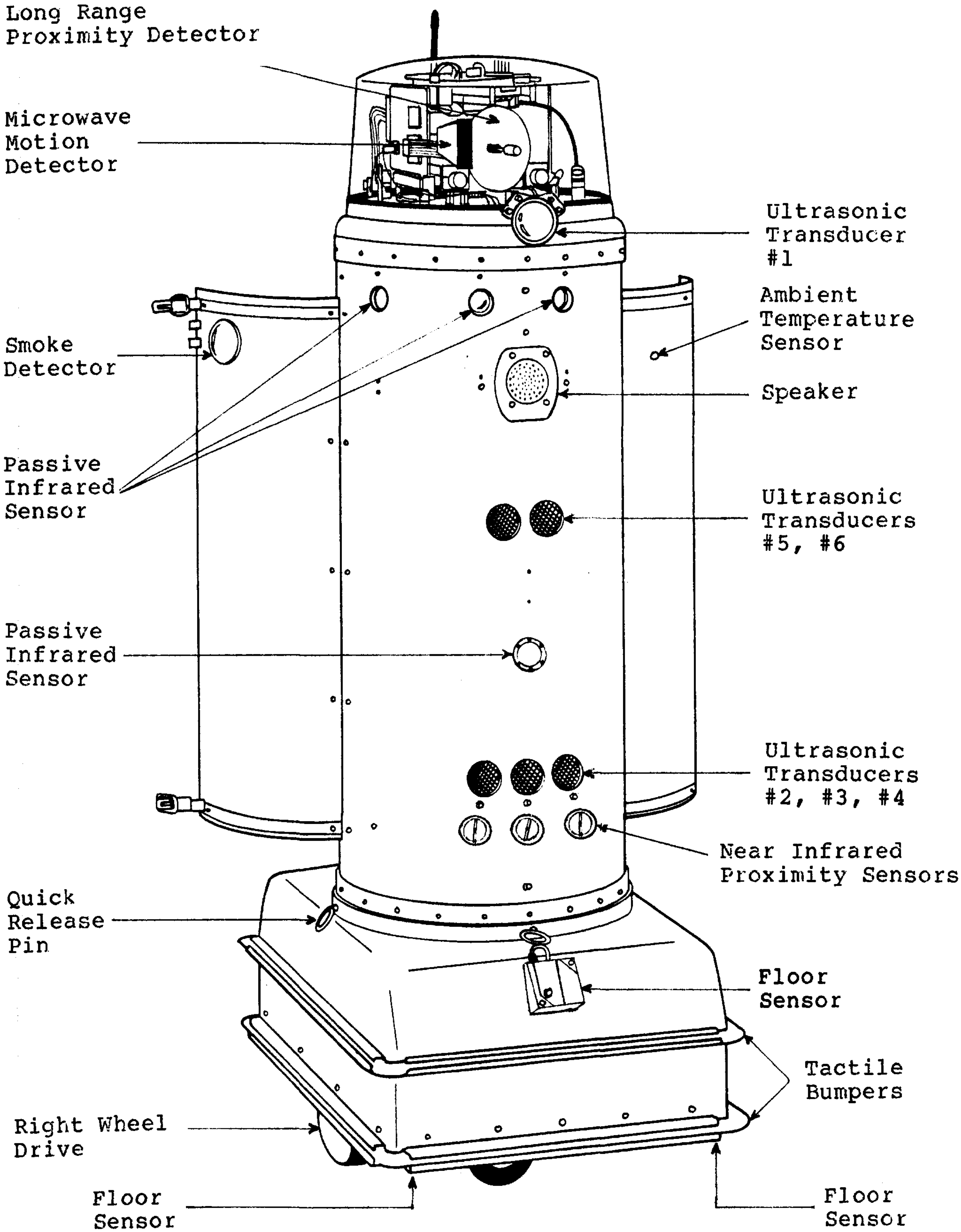
Two separate drive motors provide for differential steering, allowing the robot to turn in place with markedly improved maneuverability, greater speed, and extended range. The entire unit is a vastly improved mechanical design housed in a rugged and durable plastic and fiberglass body. Special internal circuitry checkpoints are analyzed by self diagnostic software, and operator assistance is requested if necessary through speech synthesis.

An array of five ultrasonic ranging transducers is installed on the front of the body trunk to provide distance information to objects in the path of the robot. The sequentially fired array is controlled by a dedicated microprocessor, which performs all time-to-distance conversions and then passes the range information up the control hierarchy to the scheduling microprocessor. A sixth ranging unit is located on the rotating head assembly, allowing for range measurements to be made in various directions as required.

There are numerous problems associated with ultrasonic ranging systems operating in air, to include beam divergence, specular reflection, adjacent sensor interaction, temperature dependence, and the inherently slow speed of sound. For this reason, several optically-based systems were developed for use on Robart II. A much improved version of the medium-range near-infrared proximity detector used on Robart I employs a programmable array of four high-powered LED emitters, with an increased range out to five meters. The excellent angular resolution of this sensor complements nicely the range information obtained from the ultrasonic rangefinder, and has proven invaluable as a means of gathering reliable geometric information for navigational purposes.

A stereoscopic vision system provides for additional high resolution data acquisition, and is the robot's primary means of locating and tracking the beacon on the recharging station. The system does not represent a true three-dimensional capability, however, in that each of the cameras consists of a horizontally-oriented linear as opposed to two-dimensional CCD array.

ROBART II



Long Range
Proximity Detector
Microwave
Motion
Detector
Ultrasonic
Transducer
#1
Ambient
Temperature
Sensor
Smoke
Detector
Speaker
Passive
Infrared
Sensor
Ultrasonic
Transducers
#5, #6
Passive
Infrared
Sensor
Ultrasonic
Transducers
#2, #3, #4
Near Infrared
Proximity Sensors
Quick
Release
Pin
Floor
Sensor
Tactile
Bumpers
Right Wheel
Drive
Floor
Sensor
Floor
Sensor

ROBART II (Continued)

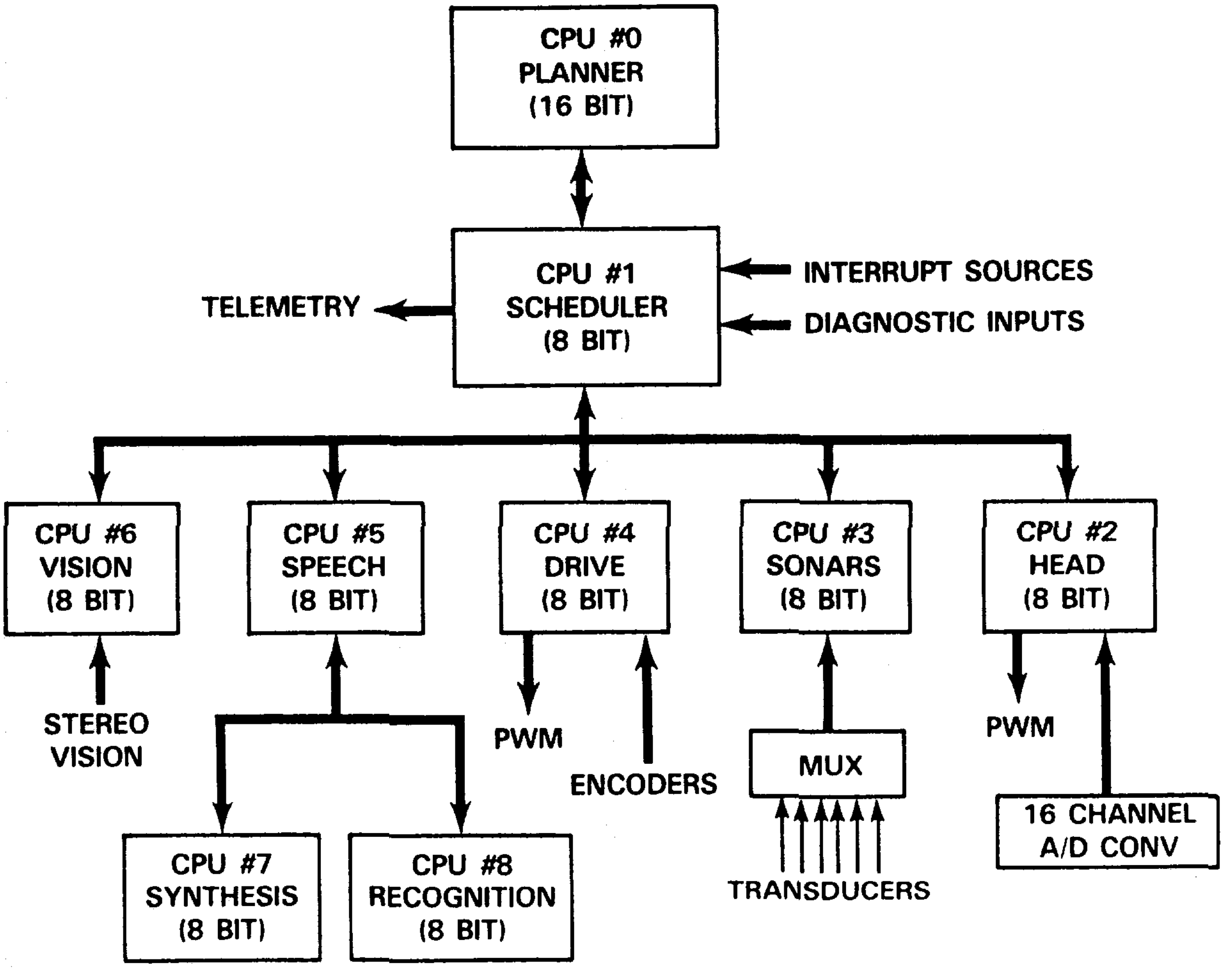
The cameras in effect provide no vertical resolution, but furnish range and bearing information on interest points detected in the horizontal plane coincident with their respective optical axes, 110 centimeters above the floor. This is consistent, however, with the two-dimensional simplified world model employed by the robot, wherein objects are represented by their projection on the X-Y plane, and height information is not taken into account.

A structured light source is employed in conjunction with these stereo cameras for ranging puposes. A 6V incandescent lamp is pulsed at about a 10 hz rate, and projects a sharply defined V-shaped pattern across the intersection of the camera plane with the target surface. This greatly improves system performance when viewing scenes with limited contrast. The incandescent source was chosen over an active laser diode emitter because of simplicity, the response characteristics of the CCD arrays, and the limited range requirements for an indoor system.

Various sensors are provided on the prototype to detect special alarm conditions, such as fire, smoke, toxic gas, flooding, vibration, and intrusion. Five true infrared motion detectors are employed to detect the presence of an intruder up to 75 feet away, reacting to the thermal radiation emitted by the human body. Four optical motion detectors and a programmable microwave motion detector mounted on the head provide additional sensing capability in this regard.

Robart II is being constructed in a modular fashion to maximize flexibility in the evaluation of specific components, such as different drive mechanisms, sensor suites, end-effectors, etc. A joint research effort with the Massachusetts Institute of Technology (MIT) Artificial Intelligence Laboratory is addressing the problems associated with autonomous navigation of such systems, and developing appropriate simulation programs and path planning algorithms. The principle researcher is Ms. Anita Flynn, a former co-op student at NSWC.

ROBART II SYSTEM ARCHITECTURE



ROBART II IS THE SECOND GENERATION VERSION OF ROBART I, AN AUTONOMOUS ROBOT DESIGNED FOR RESEARCH AND DEVELOPMENT PURPOSES. THE ARCHITECTURE OF THIS SENTRY ROBOT, CONSISTING OF NINE DISTRIBUTED MICROPROCESSORS, PROVIDES A SIGNIFICANT UPGRADE IN CAPABILITY MAKING POSSIBLE MORE ADVANCED CONTROL STRATEGIES AND GREATLY INCREASED DATA ACQUISITION.

ROBOTICS AND ARTIFICIAL INTELLIGENCE DATABASE

Under the direction of SEA 90G, the Robotics and Artificial Intelligence Database (RAID) was developed to promote technology transfer and facilitate the coordination of DOD-sponsored research. This on-line computer database, operational since FY 84, uses the INGRES 3.0 relational database management system. Three broad categories of information are presently implemented.

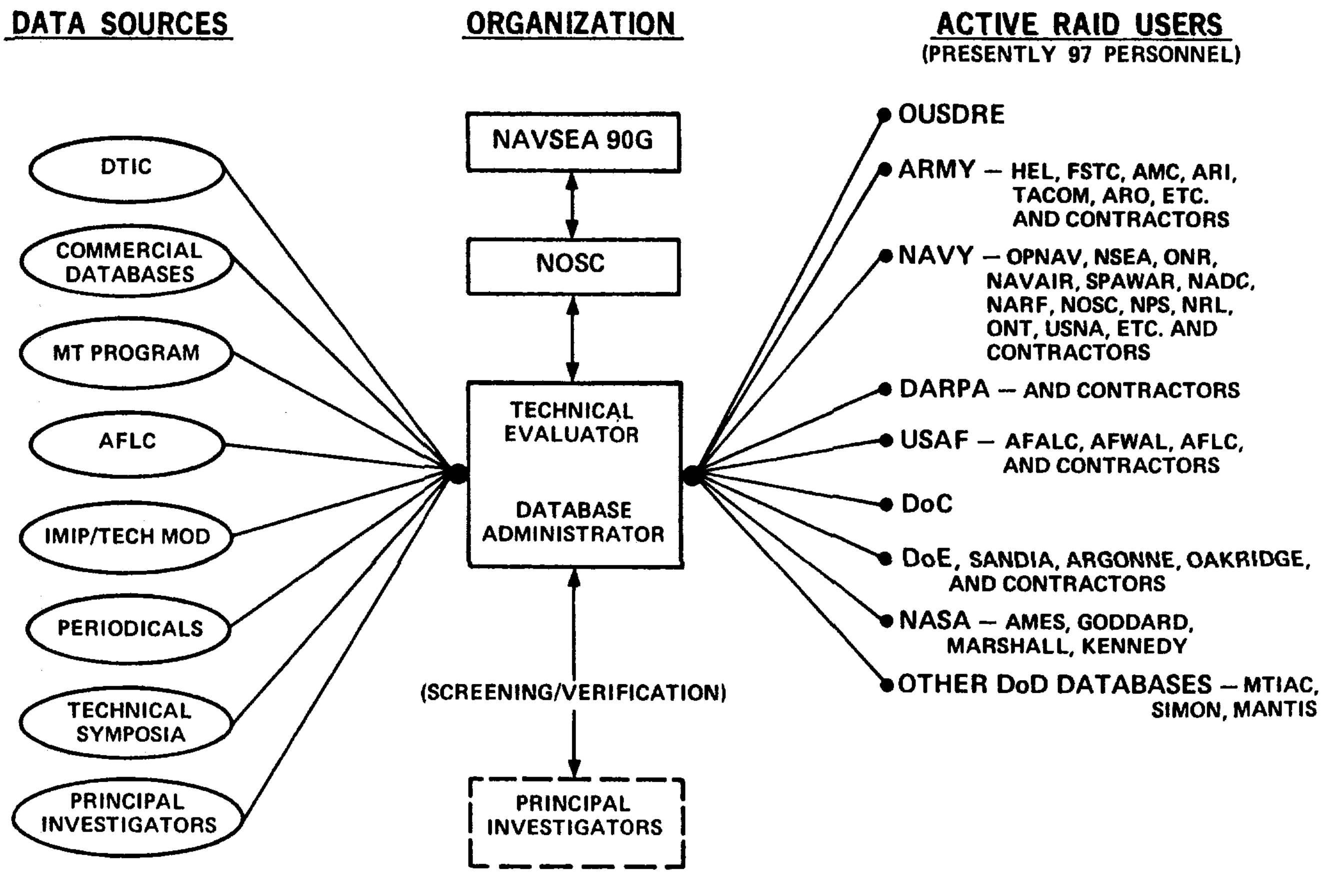
- The Project Information Section answers the "what", "for whom", and "where" questions by identifying the Principal Investigator, the sponsor, and the site of the research activity. This information is compiled from a variety of sources, including DD-1498 forms. The database search methodology is based on a project's component technology and its specific application. The financial/contractual information further expands the coverage of the organization conducting the research, provides the project's start/end dates, supplies the funding level, and displays other data pertinent to the management of the project.

- The Contacts Information Section includes the address, phone number, special interest areas, and electronic mailing address of people and organizations in the field who are associated with robotics within DOD, industry, and academia.

- The Bibliographic References Section is currently being installed, and will contain the titles, authors, and a short abstract of the work for pertinent robotics/artificial intelligence literature from both DOD and private sources. When complete, this section will be linked to the technical libraries at NSWC (Robotics) and NRL (Artificial Intelligence) through a microfiche archiving system.

RAID is installed on a VAX-11/780 computer at the Naval Ocean Systems Center (NOSC), San Diego, California. NOSC was chosen for this role by SEA 90G because of active programs in robotics and artificial intelligence, plus experience in telecommunications and database management. RAID currently contains more than 700 projects. Points of contact available through the database number greater than 1,000, while the number of registered user organizations is approximately 50. RAID is accessible through the MILNET/ARPANET military communications network and NOSC will arrange installation of electronic mail service to users who do not have it at their site. Non-government users without MILNET access can obtain RAID information through the Defense Technical Information Center (DTIC). The U. S. Army and the Defense Advanced Research Projects Agency (DARPA) have joined SEA 90G in sponsoring this project, and RAID serves as the official database for the tri-service Joint Technology Panel for Robotics (JTPR).

ROBOTICS/ARTIFICIAL INTELLIGENCE DATABASE



PURPOSE

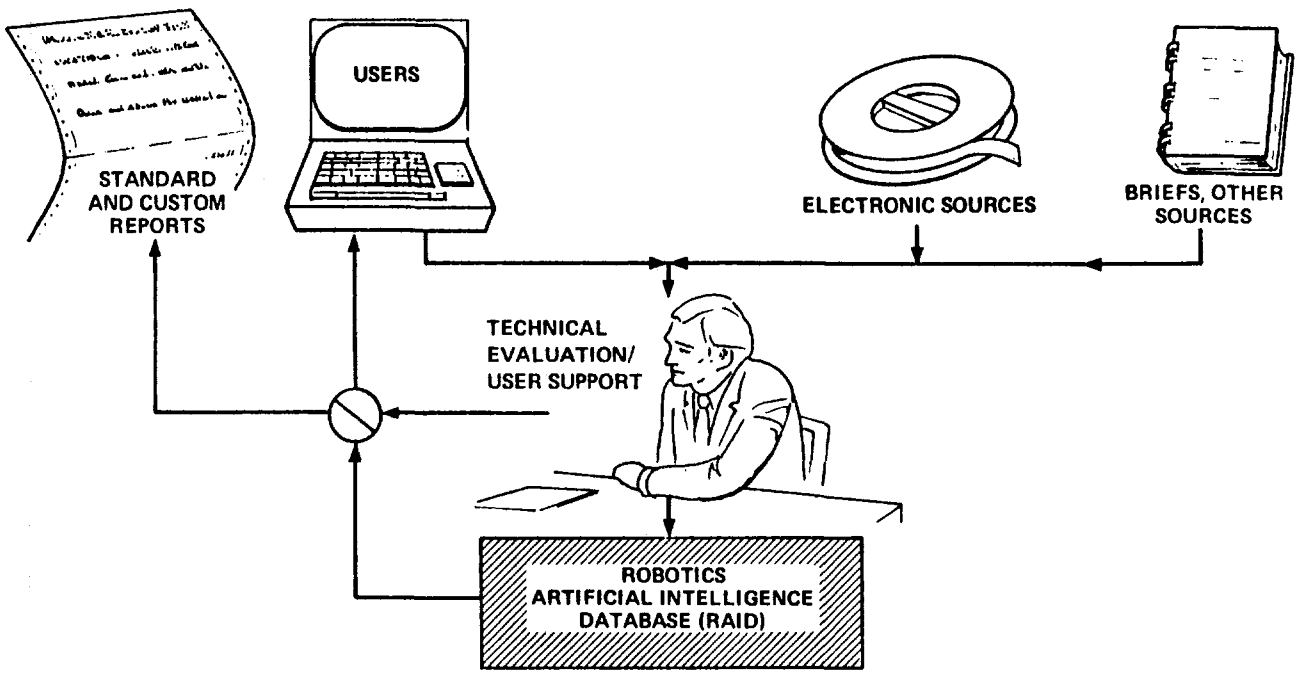
- CENTRALIZED REPOSITORY OF PAST, PRESENT AND PROPOSED DoD ROBOTIC/ARTIFICIAL INTELLIGENCE PROJECTS
- SHARE TECHNOLOGY AND COORDINATE DEVELOPMENT ACTIVITIES
- REDUCE DoD-WIDE PROJECT DUPLICATION
- SUPPORT AND AUGMENT DoD ROBOTIC/ARTIFICIAL INTELLIGENCE DEVELOPMENT
- PROVIDE ELECTRONIC COMMUNICATION AMONG TECHNOLOGISTS/ MANAGERS

ROBOTICS AND ARTIFICIAL INTELLIGENCE DATABASE (Continued)

On-line help is available in the use of all features of RAID. This is augmented by a comprehensive Users Manual which is periodically updated. Customized search services are provided by the RAID administrator for users who request such assistance. Also, a current calendar of conferences and meetings pertaining to robotics and autonomous systems is available on-line. Finally, a Management Information System module that will accurately reflect the use of RAID is in the planning stages.

With the data collection, validation, storage and retrieval mechanics in place, attention will now be given to making more effective use of this singular capability. Initiatives in these areas are discussed in the Technology Transfer (page 144) and FY 86 Objectives (page 158) sections of this report.

RAID DATA FLOWCHART



RAID OPERATING ENVIRONMENT

- VAX 11/780 COMPUTER UNDER 4.2 BSD UNIX
- INGRES VERSION 3.0 DATABASE MANAGEMENT SYSTEM
- MILNET ACCESS
- TECHNICAL/ENGINEERING SUPPORT TEAM
- FULLY AUTOMATED DATA PROCESSING SUPPORT CENTER

JOINT TECHNOLOGY PANEL FOR ROBOTICS

The tri-service Joint Technology Panel for Robotics (JTPR) was established during FY 84 by the Joint Directors of Laboratories (JDL). The charter, signed July 2, 1984, assigned broad responsibility to the JTPR to investigate ongoing and planned efforts in robotics and make recommendations to the JDL. LCDR Bart Everett, SEA 90G, was designated as the first Navy representative to this panel.

The work of the JTPR and the NAVSEA Robotics Committee is closely aligned. JTPR has a seven-part mission, first of which is to provide the JDL with recommendations for improving research and technology base resources through cooperative actions in program planning and execution. The panel is also charged with responsibility for selecting areas of robotics technology warranting multi-service attention. This calls for developing and recommending yearly joint technology base programs and to identify critical issues, deficiencies, research and technology gaps, or areas to be deemphasized. The mission also includes a responsibility for fostering and promoting cross-fertilization of all robotic research and technology base resources, including facilities, manpower and expertise, and technological programs, and to coordinate and expedite transfer of proven new technology to other service applications. Finally, the JTPR is responsible for coordinating with other JDL panels, particularly the Strategic Computing Technology Panel, to provide a coherent picture of the interrelationship of activities.

JOINT TECHNOLOGY PANEL FOR ROBOTICS

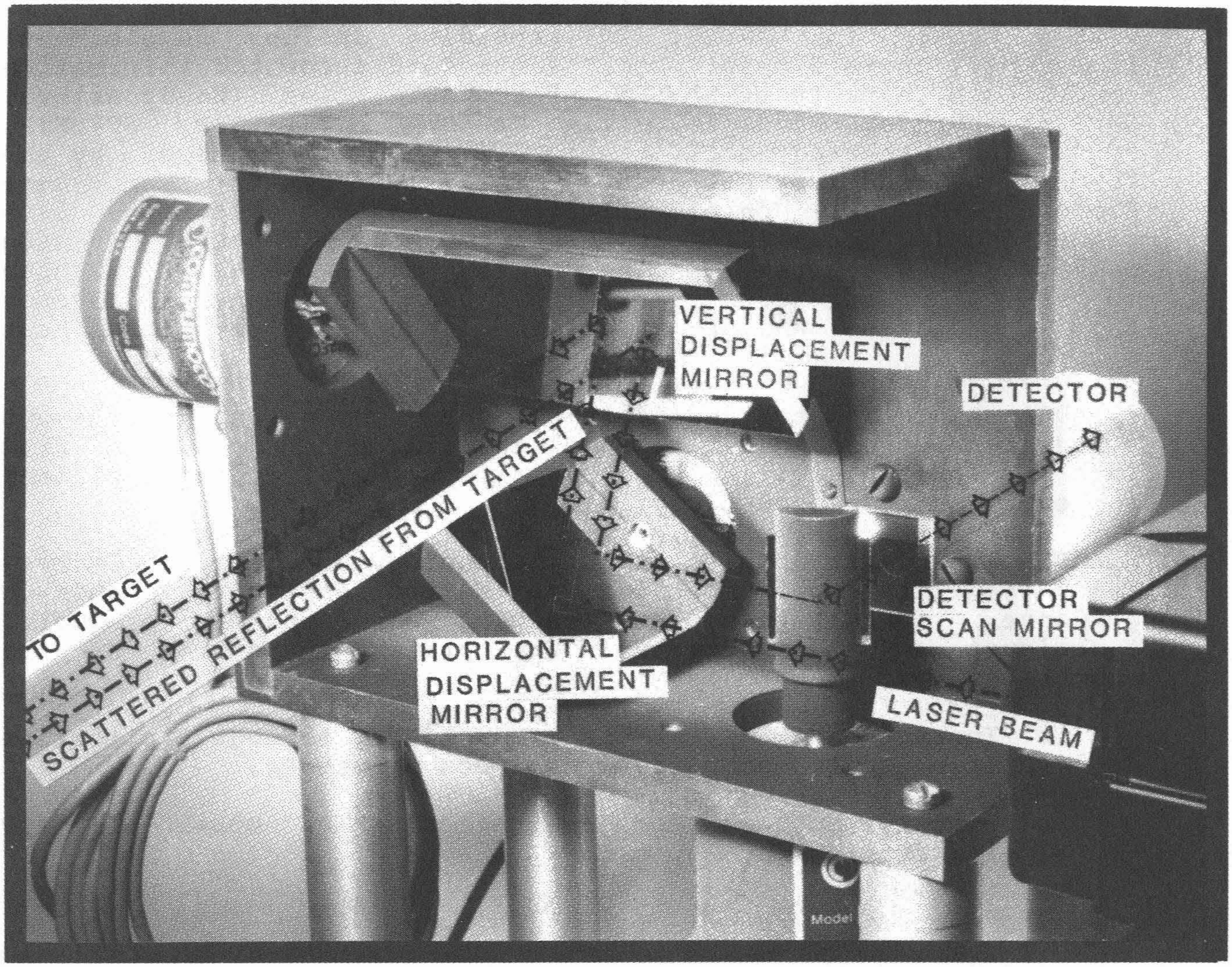
- ESTABLISHED BY JOINT DIRECTORS OF LABORATORIES
- ASSIGNED BROAD MISSION:
  - PROVIDE JDL OVERVIEW
  - IDENTIFY MULTISERVICE THRUST AREAS
  - RECOMMEND JOINT TECHNOLOGY BASE PROGRAM
  - IDENTIFY CRITICAL AREAS
  - PROVIDE TRI-SERVICE COORDINATION
  - COORDINATE TECHNOLOGY TRANSFER ACROSS SERVICE LINES
  - COORDINATE WITH OTHER JDL PANELS
- ADOPTED RAID AS OFFICIAL TRI-SERVICE DATABASE
- REPRESENTATIVES
  - ARMY - DR. JOHN D. WEISZ (CURRENT CHAIRMAN)
  - NAVY - LCDR H. R. EVERETT
  - AIR FORCE - DR. W. REIMANN, AFLC
  - MARINES - MAJOR JOE JENNINGS

ACTIVE 3-D VISION

The Active 3-D Vision System under development by Case Western Reserve University uses a laser scanning technique to view a hemispherical image space and determine the three-dimensional position and orientation of objects within that space. Special emphasis is placed on achieving the following: a) high scan speed, b) high resolution images, and c) accurate 3-D description of the image space with a minimum number of points scanned.

A pair of rotating mirrors is used to scan the beam of a low power HeNe laser across the scene of interest. The image space is segmented into a 64x64 element radial matrix. When an object intersects a matrix element and the laser beam crosses the coordinates of that element, the beam strikes the object. The object scatters and reflects the light which is collected and scanned across an optical detector by the rotating mirrors. The range to the object can then be calculated because there is an inverse relationship between the pulse-width of the captured light and the distance from the matrix intersection to the detector. This pulse-width parameter can also be used to determine the speed at which the sensor's environment can be mapped.

ACTIVE 3-D VISION



- DEVELOPMENT BY CASE WESTERN RESERVE UNIVERSITY
- CHARACTERISTICS:
  - SCANNING HeNe LASER
  - DETERMINES 3-D POSITION AND ORIENTATION OF OBJECTS WITHIN HEMISPHERICAL IMAGE SPACE
- SPECIAL EMPHASIS:
  - HIGH SPEED SCAN
  - HIGH RESOLUTION IMAGES
  - ACCURATE 3-D DESCRIPTION OF IMAGE SPACE

NAVSEA AUTOMATED DATA SYSTEM ACTIVITY

The NAVSEA Automated Data System Activity (SEAADSA), the Central Design Agency for NAVSEA, is providing design, development, implementation and maintenance of standard automated information systems in support of NAVSEA shore activities (Headquarters, Naval Shipyards, Naval Industrial Ordnance Activities, SUPSHIP, PERAs, and related activities). SEAADSA is chartered by and reports to their parent code, Information Systems Improvement Project (PMS 309) on all matters related to automated data processing (ADP) applications. The Advanced Technology Division researches, evaluates, and recommends for implementation those concepts, tools, techniques, methods, and procedures to advance the introduction and use of information technology throughout NAVSEA.

SEAADSA has completed and distributed a document on intelligent systems which examines artificial intelligence and how it fits into NAVSEA's future. Further research and evaluation is planned for expert system technology.

SEAADSA intends to develop an ADP Technology and Training Center. This facility would provide to NAVSEA employees hands-on guidance, consultation or training on computer products, techniques and advancements. The primary objectives of the center are to:

- Improve NAVSEA's mission productivity through application of automated support to business processes.

- Satisfy a need for central clearing house of ADP information and support.

NAVSEA AUTOMATED DATA SYSTEM ACTIVITY

- SUPPORTS NAVSEA SHORE ACTIVITIES PROVIDING:
  - DESIGN
  - DEVELOPMENT
  - IMPLEMENTATION
  - MAINTENANCE OF STANDARD AUTOMATED INFORMATION SYSTEMS
- RECOMMENDS IMPLEMENTATION OF TECHNIQUES TO ADVANCE THE INTRODUCTION AND USE OF INFORMATION TECHNOLOGY IN NAVSEA
- DEVELOPING AN ADP TECHNOLOGY AND TRAINING CENTER:
  - IMPROVE THE UTILIZATION OF ADP HARDWARE AND SOFTWARE TOOLS.
  - ASSIST WITH SELECTION AND CONFIGURATION OF THE RIGHT TOOL FOR THE JOB.
  - PROVIDE GUIDANCE AND ASSISTANCE IN INITIATING PROTOTYPES FOR AUTOMATING BUSINESS PROCESSES.
  - CONDUCT DEMONSTRATIONS AND TRAINING FOR SELECTED ADP DECISION SUPPORT CAPABILITIES.
  - PROVIDE GUIDANCE ON BASIC AND NECESSARY ADP PROCEDURES (E.G., BACKUP AND RECOVERY, SECURITY, STANDARDS, PROCESS DEVELOPMENT AND REFINEMENT).
  - PROVIDE FACILITY AND EXPERTISE FOR TRAINING ON MICROCOMPUTERS, WORKSTATIONS, DATA COMMUNICATIONS, GRAPHICS, EXPERT SYSTEMS, ETC.

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SECTION III - TECHNOLOGY CONCERNS

THIS SECTION ADDRESSES THE IMPORTANCE OF CONDUCTING THOROUGH TECHNOLOGY ASSESSMENTS TO ESTABLISH A BASELINE FOR FURTHER DEVELOPMENT OF APPLICATIONS OF ROBOTIC TECHNOLOGY. A SUMMARY OF CERTAIN TECHNOLOGY DEFICIENCIES IS PRESENTED, AND THE IMPORTANCE OF A WORKING TECHNOLOGY TRANSFER MECHANISM IS STRESSED.

- TECHNOLOGY ASSESSMENT
- APPLICATION STUDIES AND REPORTS
- AREAS OF NEEDED RESEARCH AND DEVELOPMENT
- TECHNOLOGY TRANSFER

TECHNOLOGY CONCERNS

TECHNOLOGY ASSESSMENT

In order for NAVSEA to adapt emerging robotic technology to applications in shipbuilding, repair, and operations, continuous effort must be directed toward refining and integrating available knowledge of technology with application needs. Technology baseline assessments are mechanisms that establish awareness of the state-of-the-art, contribute to determining whether applications are feasible, and aid in definition of technology deficiencies.

The process of discovering potential applications and updating the baseline assessment for robotic technology in the Navy is an initial step. The challenge remains to further develop the technology. A major objective is the selection, development, and implementation of robotics applications on a programmed basis. Decisions on areas to pursue must reflect an integration of needs, costs, and technological risk assessment. In evaluating the potential applications and comparing available technology to actual needs, it becomes evident that important research areas need to be addressed in order to proceed with development.

The opportunity to progress further exists. An articulation of common goals and objectives, an integrated approach to organizing project activity and the programmatic funding needed to initiate and follow through to implementation is essential. The full potential of robotics and autonomous systems cannot be realized until the program evolves from a patchwork of diverse efforts, funded from a variety of unrelated sources, to a fully funded and integrated Navy program. The FY 86 Planning Objectives (page 158) and the Out-Year Planning Initiatives (page 162) set down the initiatives and resources needed to develop the short and long term efforts required.

TECHNOLOGY ASSESSMENT

- INTEGRATION OF AVAILABLE TECHNOLOGY WITH APPLICATION NEEDS:
  - SHIPBUILDING
  - WEAPONS MANUFACTURING
  - REPAIR AND REFURBISHMENT
  - MAINTENANCE
  - OPERATIONS
- BASELINE ASSESSMENTS RESULT IN:
  - INCREASED AWARENESS OF THE STATE-OF-THE-ART
  - DETERMINATION OF FEASIBILITY OF APPLICATIONS
  - DEFINITION OF TECHNOLOGY VOIDS
  - RECOMMENDED ALTERNATE COURSES OF ACTION
  - COMMUNICATION OF FINDINGS THROUGH TECHNOLOGY TRANSFER
- TECHNOLOGY DEVELOPMENT:
  - REPRESENTS A MAJOR CHALLENGE
  - IDEALLY EVOLVES FROM TECHNOLOGY ASSESSMENT
  - REQUIRES A PROGRAMMATIC APPROACH
  - DEPENDS ON IDENTIFICATION OF NEEDED RESEARCH AREAS
- PROGRAM REQUIREMENTS:
  - FUNDING
  - INTEGRATION
  - IMPLEMENTATION

APPLICATION STUDIES AND REPORTS

An important subgoal of the Integrated Robotics Program is the need to establish a comprehensive inventory of Navy needs for robotics applications, and establish and maintain a current feasibility and cost benefit relationship between Navy needs and emerging robotics technology. During FY 85, activities within NAVSEA, other Navy offices, universities, and private industry, were reviewed to determine what developments in the robotics technology environment would apply to Navy needs. Some of the more significant reports, studies, and plans are:

CNA Research Memorandum 85-100, "Manning Implications of Enhanced Shipboard Automation in U.S. Navy Ships" - a study initiated in July 1985 at the request of the Deputy Chief of Naval Operations for Plans, Policy and Operations. The primary objective of the study was to consider general shipboard systems in which increased levels of automation are feasible and to assess the resulting manning implications.

Sensor Survey - a survey and assessment of off-the-shelf sensors suitable for collision avoidance and navigational purposes was begun by SEA 90G2 at the Robotics Laboratory, NSWC/WO for the purpose of developing a technology awareness baseline in support of mobile applications.

"White Paper" on Strategies for Development of Robotics Technology for the Navy - prepared by SEA 90G for consideration by the Office of Naval Research/Office of Naval Technology (ONR/ONT) to delineate numerous areas of needed research and development.

Robotic Developments in Support of Naval Operations - a study by Science Applications International, Inc., for SEA 90G, investigating methods to better integrate NAVSEA's future robotics efforts to address fleet operations and operational support.

Robotic Technology in Shipbuilding Applications - a report prepared by LCDR Everett, SEA 90G, and R. L. Jenkins, David Taylor Naval Ship Research and Development Center, discussing robotic applications within the shipbuilding industry. The report provides basic background on the current status of the industry, the naval ship acquisition process, and shipbuilding in general, along with brief technical descriptions of specific development projects aimed at filling some of the technological voids.

APPLICATION STUDIES AND REPORTS (Continued)

Robotics in the Navy - a two-part article written by LCDR Everett and published in ROBOTICS AGE, which provides an introduction to key Navy organizations in the robotics field, and applications being pursued by NAVSEA in industrial and non-industrial areas.

Sentry and Security Applications of Robotic Technology - an article written by LCDR Everett discussing the use of robotics technology in support of physical security needs.

Application of Robotics Technology to CW Defense in the Combat Information Center (CIC) of an LHA Class Ship - a study sponsored by NAVSEA 05R16 to develop recommendations concerning conceptual robotics/artificial intelligence systems which might be adapted to enhance performance and increase survivability of the CIC of an LHA Class Amphibious Assault Ship.

Robotics Projects for Near-Term Shipyard Implementation - SEA 90G recommended three low-risk projects to SEA 070 for immediate implementation in Naval shipyards.

Technical Overview of Intelligent Systems - a study prepared by the NAVSEA Automated Data Systems Activity (NAVSEAADSA), which triggered a coordinating conference with SEA 90G to facilitate communications and technology transfer.

Robotic Requirements Study for Shipboard Applications - a preliminary study was conducted by Odetics Corporation, under the Small Business Innovative Research (SBIR) Program, to determine the requirements for non-industrial operational applications for robotics-related technologies.

Numerous potential robotics technology application areas have been identified which merit investigation. The majority of applications under consideration involve hazardous and mundane tasks which, if successful, will free human assets to accomplish other important and productive unstructured tasks which require the essential characteristics of flexibility and judgement. Assessments, studies, and reports of this nature are a key factor contributing to technology transfer and increased awareness of the potential of robotic and autonomous systems in Navy applications.

NAVAL OPERATIONS SUPPORT

During FY 85, Science Applications International Corporation (SAIC) was tasked by SEA 90G to conduct a four-part study on robotics development in support of naval operations. The study included an assessment of robotics/advanced automation related to this arena, and identified NAVSEA considerations for application of that technology to the Navy operational environment. The study also examined ongoing non-industrial robotics projects sponsored by NAVSEA to identify technical and programmatic obstacles impeding the projects' progress. The findings of those examinations were used to construct a workable model for management of future non-industrial robotic development efforts.

Robotic systems developed for Navy non-industrial use must meet performance requirements for military systems in general, but special attention must be devoted to some aspects of that development. Project managers and other personnel interviewed in the course of the study believed that robotic systems can one day effectively perform a variety of missions. Supportability of robotic systems, however, was a major concern of those interviewed. Specifically, there was concern that manpower requirements might increase, systems might not have high levels of availability, and the supply system might not be adequate to provide necessary parts support. The other major considerations for NAVSEA use of robotic systems were for tolerance of the marine environment, and interface with current ship designs. These issues must be formally addressed in the robotic system development process. Progress in developing robotic systems with necessary attributes must be widely publicized to assure NAVSEA program managers that robotic systems can be successfully applied to operational needs.

Nine ongoing non-industrial robotics development projects were examined by the SAIC report. It is notable that all of the projects involve mobile platforms and remote control. Similarities indicate that considerable savings could result from exchange of technical information among organizations developing robotic systems.

The report summarized that NAVSEA should take advantage of the potential of robotics technology to effectively meet the increasing demands of the Navy in an environment of limited resources. The problem is to identify the appropriate places for application of that technology. Once worthwhile applications have been identified, NAVSEA can develop the appropriate systems under the existing organizational structure, with support from in-house robotics experts in SEA 90G. The development process can be accelerated by SEA 90G via improvements in communication between technical and management communities.

NAVAL OPERATIONS SUPPORT

- ROBOTICS DEVELOPMENT IN SUPPORT OF NAVAL OPERATIONS

- PREPARED BY SCIENCE APPLICATIONS INTERNATIONAL CORPORATION (SAIC)

- EXAMINED NINE ONGOING NON-INDUSTRIAL ROBOTICS DEVELOPMENT PROJECTS:

  - REMOTE CONTROL FIREFIGHTING PLATFORM (RCFP)
  - ADVANCED UNDERWATER SEARCH SYSTEM (AUSS)
  - FREE SWIMMING VEHICLE
  - ADVANCED DEVELOPMENT REMOTELY OPERATED VEHICLE (ADROV)
  - REMOTELY OPERATED VEHICLE FOR EMPLACEMENT AND RECONNAISSANCE (ROVER)
  - SEMI-AUTONOMOUS MOBILE SYSTEM FOR ORDNANCE NEUTRALIZATION (SAMSON)
  - REMOTE CONTROL RECONNAISSANCE MONITOR (RECORM)
  - REMOTELY OPERATED MOBILE EXCAVATOR (ROME)
  - HEAVY EQUIPMENT REMOTE CONTROL (HERC)

- SIMILARITIES INDICATE SAVINGS POTENTIAL THROUGH EXCHANGE OF TECHNICAL INFORMATION

MANPOWER, PERSONNEL, AND TRAINING

The Deputy Chief Engineer for Logistics (CHENG/L), Manpower, Personnel, and Training (MP&T) Division has initiated a Robotics Manpower, Personnel, and Training Impact Analysis, at the request of SEA 90G, to determine future MP&T requirements. John Gorman (CEL-MP-16) is the project manager for this effort.

The effectiveness of a new system often depends on how well it interfaces with the human operator and maintenance technician. Too often this relationship is overlooked until late in the acquisition process, and as a result the system, when introduced into the fleet, fails to meet its performance goals or requires extensive manpower/skill support. This situation places an additional burden on already taxed skill inventories, requires expensive training pipelines, yet is in most cases avoidable.

Early identification of MP&T requirements can help eliminate these problems through better planning and more efficient use of resources. Additionally, early MP&T identification can provide input for consideration in the design of a system. Requirements for new systems will form one of the major thrusts of the Robotics MP&T effort and will be determined using a baseline comparison system methodology. The results of these analyses will identify the need for new skill requirements, determine training concepts, and provide estimates of required MP&T fiscal and personnel resources. MP&T requirements will also be examined with respect to projected future requirements. This information will be useful to decision makers in selection of a design option. These will be ongoing efforts in FY 86.

The other thrust of this effort is development of a general training criteria. Based on analysis of individual system requirements, this study will identify requirements that are common to a number of systems. This data will be used to form a generic training pipeline. This type of training reduces the need to teach similar skills in individual courses and is therefore more cost effective. This will be a continuing effort as systems data becomes available.

MANPOWER, PERSONNEL, AND TRAINING

- ROBOTICS MANPOWER, PERSONNEL, AND TRAINING (MP&T) ANALYSIS INITIATED BY NAVSEA DEPUTY CHIEF ENGINEER FOR LOGISTICS

- MAN/MACHINE INTERFACE RELATIONSHIP OFTEN OVERLOOKED:

  - PERFORMANCE GOALS IMPACTED
  - MAY REQUIRE EXTENSIVE MANPOWER/SKILL SUPPORT

- EARLY IDENTIFICATION OF MP&T REQUIREMENTS ESSENTIAL:

  - ESTABLISH INPUT NECESSARY TO SYSTEM DESIGN
  - IDENTIFY SKILL REQUIREMENTS
  - EXPLORE TRAINING CONCEPTS
  - DETERMINE NEEDED FISCAL AND PERSONNEL RESOURCES

- DEVELOPMENT OF GENERAL TRAINING CRITERIA:

  - DEFINE COMMON SYSTEM REQUIREMENTS
  - ESTABLISH GENERIC TRAINING PIPELINE

ROBOTIC REQUIREMENTS STUDY FOR SHIPBOARD APPLICATIONS

The Small Business Innovative Research (SBIR) program sponsored by the Department of Defense encourages small business firms with strong research and development capabilities to submit proposals on innovative concepts related to important defense-oriented scientific or engineering problems. The SBIR program has provided an effective mechanism for initiating studies and programs in supporting robotic technologies.

The Robotics Lab at the Naval Surface Weapons Center, White Oak, MD acted as project manager for the "Survey of Robotic Requirements for Naval Firefighting and Other Shipboard Applications" as a part of a NAVSEA-sponsored SBIR effort. The Phase I study was conducted by Odetics Corporation of Anaheim, CA to investigate requirements for non-industrial applications for robotics-related technologies. The effort supplemented NSWC's Firefighter Program (which transitioned from NAVSEA to NAVAIR in FY 85) and examined potential applications to other shipboard hazardous duty operations as well.

Current shipboard firefighting procedures and requirements were compiled and examined. In addition, a top-level investigation of other potential applications was made in order to identify those with benefits (especially for manpower reduction) for short-term development and demonstration tests. The most promising of these areas were battle damage investigation and control, operations under nuclear/chemical/biological warfare conditions, explosive ordnance handling, and security/sentry functions.

A proposal to develop specific application concepts based on this initial survey will be evaluated for Phase II continuation of this SBIR effort.

INTERMEDIATE MAINTENANCE ACTIVITY AUTOMATED WORKCENTER

SEA 56X52, when funded, plans to install two computer numerical control (CNC) turning centers at the Intermediate Activity Maintenance (IMA) level for shipboard test and evaluation in support of a tentative operational requirement (TOR) for a FY 90 AR ship design. One turning center will be installed on a destroyer tender and one on a submarine tender. These turning centers are commercially available with a CNC controller having interactive graphics and user-friendly programming. This program will introduce numerical-controlled machine tools to the ship environment in order to determine the impact on sailor-machine and machine-ship interface problems and issues involving training, rework, repeatability, quality assurance, operational availability, logistics and maintenance.

ROBOTIC REQUIREMENTS STUDY FOR SHIPBOARD APPLICATIONS

- SURVEY OF NAVY ROBOTICS REQUIREMENTS:
  - INVESTIGATED REQUIREMENTS FOR NON-INDUSTRIAL APPLICATIONS
  - NAVSEA-SPONSORED SMALL BUSINESS INNOVATIVE RESEARCH (SBIR) PROGRAM
  - PRELIMINARY STUDY BY ODETICS CORPORATION
  - COMPILED CURRENT SHIPBOARD FIREFIGHTING PROCEDURES AND REQUIREMENTS
  - INVESTIGATED POTENTIAL APPLICATIONS FOR SHORT TERM DEVELOPMENT AND DEMONSTRATION TESTS

- PROMISING AREAS:
  - BATTLE DAMAGE INVESTIGATION AND CONTROL
  - OPERATIONS UNDER NUCLEAR/CHEMICAL/BIOLOGICAL CONDITIONS
  - EXPLOSIVE ORDNANCE HANDLING
  - SECURITY/SENTRY FUNCTIONS

INTERMEDIATE MAINTENANCE ACTIVITY AUTOMATED WORKCENTER

- TEST AND EVALUATION OF COMPUTER NUMERICAL CONTROL TURNING CENTERS IN SHIPBOARD ENVIRONMENT

- DETERMINE IMPACT ON:
  - SAILOR-MACHINE INTERFACE PROBLEMS
  - MACHINE-SHIP INTERFACE PROBLEMS
  - SAILOR TRAINING ISSUES
  - REDUCTIONS IN MATERIAL SCRAP AND REWORK ISSUES
  - INCREASED REPEATABILITY ISSUES
  - INCREASED QUALITY ASSURANCE ISSUES
  - OPERATIONAL AVAILABILITY (Ao) ISSUES
  - LOGISTICS AND MAINTENANCE ISSUES

TECHNOLOGY CONCERNS: AREAS OF NEEDED RESEARCH AND DEVELOPMENT

ROBOTIC TECHNOLOGY

Question: What is meant by the term "robotics technology"?

Attempts to define a "robot" have been made by many organizations, including the Robotics Industries Association and the Naval Air Systems Command. None of these definitions are adequate for Navy-wide use in both the industrial and non-industrial sense.

- Industry definitions lack operational (non-industrial) orientation.
- Service definitions do not adequately address military manufacturing and repair (industrial) applications.

The Joint Technology Panel for Robotics (JTPR), on behalf of the Joint Directors of Laboratories (JDL), has established the following definition of a robot:

> "A system incorporating a computer controller to provide autonomy and reprogrammability, which employs an end-effector of some type (manipulator arm or mobile platform), which exhibits flexibility in the roles which it can perform or the equipment with which it interfaces, and which performs tasks of a complexity level that previously required human control."

The issue, however, is not really the definition of a "robot", but rather what is meant by "robotic technology." The field of robotics (assume for now the JTPR definition) is supported by the disciplines of mathematics, computer science (to include artificial intelligence), mechanical and electrical engineering, materials, physics, psychology, and anatomy. These supporting disciplines required to construct a mechanical system, endow it with intelligence, and provide the necessary sensor data upon which to act, can collectively be termed robotic technology.

There is no universally accepted definition of a "robot", but that put forth by the JTPR appears the most appropriate for this discussion. Revision of the JTPR definition will add confusion, but will not necessarily gain acceptance.

All the supporting disciplines contributing to the successful fielding of an intelligent system as so defined can be considered "robotic technology" when thus employed.

The JTPR's definition of robotics should be used to facilitate determination of technologies that should be pursued in support of robotics system development.

TECHNOLOGY CONCERNS: AREAS OF NEEDED RESEARCH AND DEVELOPMENT

ROBOTIC TECHNOLOGY DEFICIENCIES

Ongoing 6.3 development efforts have shown the requirement for more supportive 6.1 and 6.2 research. For the increasing number of identified potential Navy applications, there are known deficiencies in supporting technologies that will impede, if not preclude, successful implementation of robotic solutions. These can be subdivided into two general categories: "Industrial" and "Non-industrial". The examples cited below can be traced to specific prototype development needs in existing NAVSEA programs. The centralized development of generic technology in response to these issues will result in substantial cost savings to the Navy through avoidance of unwanted redundancy. Additional cost savings will be realized through the attainment of application goals otherwise not technologically feasible.

NAVY-UNIQUE INDUSTRIAL NEEDS

For the most part these needs reflect fundamental differences between conventional high-volume assembly-line scenarios found throughout industry, and very low volume, unstructured environments of Navy applications in manufacturing and repair. It is this latter area where the major impact of robotics on the Navy is predicted to occur. This arena has been virtually untouched by industrial developments. Examples of needed research are:

On-line Programming Techniques - Acceptable methods must be developed to allow faster programming for low volume applications. Conventional teach pendants employed by industry are impractical in Navy scenarios. Options include laser-based target designation systems, six degree-of-freedom joysticks, voice input, etc.

Off-line Programming Techniques - Practical methods must be devised to provide three-dimensional data describing part geometries for use in generating robot motion programs. This requires interfacing with, and augmenting, existing and future computer-aided-design (CAD) systems, and development of volumetric digitizing techniques and sensors. In addition, process control information depicting parameter values and sequence of operations must be clearly presented in the design database to allow intelligent robotic systems to address low volume, unstructured scenarios typical of Navy applications.

Path Planning for Industrial Robots - Appropriate algorithms must be developed to automatically generate optimum manipulator and end-effector responses from geometric and process control data discussed above.

NAVY-UNIQUE INDUSTRIAL NEEDS (Continued)

Collision Avoidance - Specialized algorithms must be devised to ensure robot motion trajectories and process sequences calculated in an off-line mode do not create hazardous situations in terms of damage to the workpiece, equipment, or operating personnel. This requires extensive dynamic modeling of robotic systems, workpieces and associated environments.

Sensors to Support Collision Avoidance - Three-dimensional imaging sensors are required to determine part location and orientation for input to the collision avoidance software routines, as well as identify discrepancies between expected and actual conditions.

Real Time Process Control Sensors and Algorithms - Automatic and adaptive process control is essential if robotic systems are to be employed in Navy industrial scenarios, due to unstructured and changing working environments. Research issues include, but are not limited to, weld pool imaging systems, infrared thermography, paint thickness gauging, surface cleanliness sensors, and non-contact measurement techniques, seam tracking systems and weld process control strategies. Typical applications include surface preparation and coating, gas metal arc welding, laser metalworking, application of flame sprayed coatings, grinding and polishing, non-destructive testing, etc.

Dynamic Control Techniques - This is a critical research issue needed to support design of large robotic systems capable of dealing with massive workpieces as encountered in ship and weapons system manufacturing and repair scenarios. Conventional industrial robots have in comparison, rather limited working envelopes. They can therefore assign constant values to control system parameters and mechanical properties such as moments of inertia, static and dynamic frictional forces. In reality, however, these entities are not fixed values, but functions of manipulator and end-effector position, velocity, and acceleration, and are further affected by changing payloads. Accuracy, repeatability, and system response degrade measurably as real world conditions vary from ideal assumptions, and large systems will require real time calculation of servo control mechanism transfer functions (i.e., gains, damping coefficients, etc.) in order to compensate.

Computer Simulation of Robotic Devices - Much work is needed in this area to provide generic tools needed for off-line programming, collision avoidance, path planning and dynamic control research.

NAVY-UNIQUE INDUSTRIAL NEEDS (Continued)

Generic Rule-Based Architectures - The development of a generic system architecture for networking a modular collection of expert systems with appropriate modular sensor and controller subsystems is viewed as necessary and desirable for complex Navy applications. Such an architecture would provide for inherent standardization and allow for evolutionary system upgrades in response to componentry improvements. The rule-based expert systems address the CAD interface, path planning, collision avoidance and scheduling functions discussed above, and could be modified through rule changes to accommodate different system applications without extensive redesign.

Expert System Development - Generic research in expert system development is mandatory for providing required system intelligence to allow conventional robotic systems to address complex Navy needs in a practical fashion.

Ship Motion Effects - Research is needed to investigate effects of ship motion on robot dynamics and equipment life.

NON-INDUSTRIAL NEEDS

The following research needs are required to support operational applications of robotics, embodied for the most part in mobile systems. Initial emphasis in prototype development will address hazardous operations (EOD, NBC scenarios) and performance of tasks for which man is incapable. As advances are made in supporting technologies, there will be a natural trend from teleoperated to semi-autonomous and autonomous systems.

Collision Avoidance for Mobile Robots - Regardless of application, an essential technological need for any system involving mobility will be the capability to avoid impact with surrounding objects. The problems associated with this need are two-fold: 1) acquisition of high resolution geometric data describing the environment, and 2) computational resources needed to interpret that data.

Sensors to Support Collision Avoidance - The acquisition of geometric data requires development of high resolution, low cost non-contact ranging systems capable of real time operation. Ultrasonic ranging systems have served in this capacity, but suffer from problems associated with extremely poor angular resolution, temperature dependence, specular reflection, NON-INDUSTRIAL NEEDS (Continued)

interference from adjacent units and the relatively slow speed of sound in air. Conventional laser rangefinders are prohibitively expensive in terms of initial costs, physical size and energy requirements. Practical units must be employed in sufficient numbers to rapidly acquire geometric data for use in modeling the robot's surroundings, to support decisions on terrain traversibility, and to address environmental awareness in general.

Navigational Planning for Mobile Robots - Mobile autonomous and teleoperated systems must be capable of determining their exact location as well as orientation at that location in order to effectively maneuver to a desired position to circumvent known obstructions or hazards, or to avoid detection. Secondly, these systems calculate the optimum path for traversing from their current location to the goal, a task which is computationally exhausting.

Sensors to Support Navigational Planning - The task of ascertaining position and orientation will require development of low cost, accurate and reliable sensors and/or navigational aids currently unavailable.

Computational Resources - Improved data processing techniques and pipeline and parallel processing architectures must be developed to handle the massive amounts of data, calculations, and symbolic reasoning needed to emulate the required degree of intelligence for even the most primitive of systems. This is especially critical for a mobile system, where space and energy resources are at a premium.

Application Specific Sensors and Controls - This is the non-industrial analogy to process control sensors in the industrial sense. For a given functional application (firefighting, sentry and security functions, explosive ordnance disposal, mine placement and neutralization, undersea search and recovery, airborne sensor platforms, underwater sensor platforms, weapons handling, material handling, nuclear maintenance, containment, surveillance, etc.) an appropriate sensor suite and associated intelligence will be required.

Motion Effectors - Research is needed to further develop various types of motion effectors (tracked, wheeled, legged, omnidirectional) for optimal maneuverability, dexterity, traction, etc.

NON-INDUSTRIAL NEEDS (Continued)

Energy Sources - Mobile systems will require a practical onboard source of energy to support drive mechanisms, actuators, sensors, and computational resources.

Man-Machine Interface - Considerable research is needed in this area to effectively enhance the human transfer function and allow efficient interaction between the operator and complex teleoperated and semi-autonomous systems under development.

Training and Self-Diagnostics - The importance of this area cannot be overemphasized. Robotic systems of the future will by necessity be complex in nature, and not well understood by their users. Substantial gains in productivity, quality, or safety could be easily offset by problems associated with operator training, system integration and maintenance and repair. It is impractical to attempt to provide skill levels needed to support such equipment through conventional means. Such action would be prohibitively expensive, and even if theoretically possible would suffer from almost certain loss of highly trained personnel to better paying jobs in industry. Therefore, proposed systems must be fully proficient in diagnosing their own problems. Video disk technology and expert systems must be developed for training and instruction to overcome this problem.

TECHNOLOGY CONCERNS

TECHNOLOGY TRANSFER

One of the most important and difficult tasks in any research and development program is to successfully transfer technology which was developed, tested, and approved in one environment to an application in another. The developing activity may not have incentive to expend resources on what is perceived to be an effort with no pay-off. The potential receiver, on the other hand, prefers to be free to develop their own technology. The NAVSEA Robotics Program consists of a large number of relatively independent projects with great commonality of generic technology. An effective technology transfer capability is therefore an essential objective.

Several important aspects of that capability are in place, including the Robotics/Artificial Intelligence Database (RAID), the Robotics Reference Library, and the NAVSEA Robotics Committee. These represent the foundation of the technology transfer function. A climate where prospective users have timely access to high quality project data, and are motivated to investigate the applicability of the new technology, will reduce the expenditure of resources on redundant efforts while enhancing the decision making process.

The thrust of the NAVSEA Integrated Robotics Program therefore is not only to identify potential Navy robotics applications and technology voids, but also to be able to provide a mechanism to effectively transfer technology to the users. To accomplish this, users need to be involved in the process, working parallel with the developers to ensure a smooth handoff. The users early involvement enhances the design and fit between available technology and the proposed application and implementation.

Implementation of a sound idea may falter because of failure to appreciate the importance of advanced preparation. Technical superiority alone will not guarantee acceptance. The implementation processes require a supportive infrastructure and resources to prepare and carry it through to completion. As the environment changes and resources become more limited, the pressures on building and maintaining ships and weapon systems at a high state of readiness become acute. Meanwhile, as the availability of new technologies accelerates, the challenges to find, select and implement the most appropriate technology increases. The situation demands an approach creative and flexible enough to adjust to changing conditions, while focusing continuously on application of robotics technology to improve quality and performance of Navy ships and weapon systems, simultaneously reducing costs, increasing effectiveness and enhancing safety.

SECTION IV - SUMMARY, CONCLUSIONS AND PROJECTIONS

THIS SECTION SUMMARIZES PROGRESS MADE IN FY 85, PRESENTS A PROGNOSIS, REPORTS ON LESSONS LEARNED, DISCUSSES NEAR-TERM CHALLENGES, AND CONCLUDES WITH AN IDENTIFICATION OF THE KEY FY 86 PLANNING OBJECTIVES AND OUT-YEAR PLANNING INITIATIVES, WITH DEPICTIONS OF THE ORGANIZATIONAL MODEL FOR EXERCISING THE PROGRAM PLANNING APPROACH.

- PROGRAM STATUS OVERVIEW
- LESSONS LEARNED
- APPLICATION/TECHNOLOGY MISMATCH CONCERNS
- PROGNOSIS
- FY 86 PLANNING OBJECTIVES
- OUT-YEAR PLANNING INITIATIVES
- THE PLANNING MECHANISMS
  - THE TECHNOLOGY DEVELOPMENT MODEL
  - THE PLANNING SCENARIO
  - THE PROJECT INTEGRATION MATRIX

SUMMARY, CONCLUSIONS AND PROJECTIONS

PROGRAM STATUS OVERVIEW

During FY 85, a major effort was made to define the comprehensive mission of the Naval Sea Systems Command Integrated Robotics Program. This effort was motivated by pressure to seek out viable applications of robotics technology -- applications meeting demands for increased efficiency and productivity vital to maintaining a high state of readiness while combatting rising life cycle costs.

The search for robotics technology applications quickly focused on the robotics projects underway at NAVSEA. However, it became apparent that many technology deficiencies existed in both the industrial and non-industrial categories; our knowledge of technology applications lagged our understanding of technology deficiencies.

The NAVSEA projects addressed in Section II represent a 30 percent increase in activity over the previous year. Recognizing that the NAVSEA Robotics Program is not a major system acquisition program, but a variety of ongoing efforts, it is apparent that obtaining a clear picture of the NAVSEA robotics effort is a complex task. An increase in the use of robotic alternatives by NAVSEA is clearly in evidence and the implications are important. As the demand to implement robotic solutions throughout the Command increases, more projects must be examined with the full knowledge of existing robotics technology available.

The Office of Robotics and Autonomous System's work to identify and assess available robotic technology has led to the development of a structured approach for technology assessment, applications studies, focused R&D and demonstration projects. This model may well be the prototype for future Navy-wide assessments. NAVSEA's robotics efforts, coupled with the involvement of the Joint Technology Panel for Robotics, the various Navy laboratories, OPNAV, and other commands, has increased the SEA 90G workload significantly, but has greatly enhanced awareness, not only at NAVSEA, but Navy-wide.

Assessing current projects and establishing a clear understanding of technology voids is vital, but the search for viable applications of robotics technology applications must go on as well. The importance of establishing a functional technology transfer mechanism is essential to linking needs and capabilities. The Robotics and Artificial Intelligence Database is a key mechanism for the sharing of information within the Navy industrial and operational communities.

The need to validate high-return robotics applications is growing rapidly. A clear understanding of both available technology capabilities and deficiencies, a mechanism to assess performance of ongoing efforts, the defining of Navy-unique research and development requirements, and an active technology transfer program are all essential elements in meeting these needs.

PROGRAM STATUS OVERVIEW

- FY 85 WAS A YEAR OF PROGRESS:
  - CONSOLIDATION OF NAVSEA ROBOTICS PROGRAM
  - IDENTIFICATION OF OVER 65 EXISTING NAVSEA ROBOTICS PROJECTS
  - INTEGRATION TO ENHANCE TECHNOLOGY TRANSFER
- AREAS OF EMPHASIS:
  - ESTABLISHING AWARENESS OF ROBOTICS TECHNOLOGY
  - IDENTIFICATION OF ROBOTIC APPLICATIONS
  - UNDERSTANDING OF TECHNOLOGICAL VOIDS
  - MATCHING NEEDS TO AVAILABLE TECHNOLOGY
  - ASSESSING PERFORMANCE OF ONGOING EFFORTS
  - DEFINING NAVY-UNIQUE RESEARCH AND DEVELOPMENT NEEDS
- ROBOTIC EXPLORATORY GROUP OF NAVAL STUDIES BOARD CONCLUDED:
  - ROBOTIC TECHNOLOGIES HAVE HIGH DEGREE OF APPLICABILITY TO NAVAL OPERATIONS
  - HIGH RETURN APPLICATIONS WILL REQUIRE NAVY DEVELOPMENT

SUMMARY, CONCLUSIONS AND PROJECTIONS

LESSONS LEARNED

The NAVSEA Robotics Program is built on a foundation of centralized policy guidance and decentralized execution, strongly exercised by the project managers. Growing from initial efforts defining goals and objectives, to a dynamic involvement in over sixty-five projects covering several functional areas, has been a significant learning experience. It is clear that good communications and feedback between all parties are essential. At all levels, a thorough understanding of capabilities, coupled with an appreciation of needed applications and technology deficiencies, is a prerequisite to development of a balanced and workable long-term robotics plan.

Without a doubt, the most valuable lesson learned is that the development of a comprehensive baseline assessment is integral to the understanding of technology applications and deficiencies. Further, the project managers must be included in the initial planning stages, possess a working knowledge of the technology, and actively use the resources of the Office of Robotics and Autonomous Systems, the Robotics Committee, and the Robotics and Artificial Intelligence Database (RAID). Project managers are normally so overburdened with their own problems on a daily basis that they are not inclined to seek outside involvement that might produce shortcuts to technology development/acquisition.

Another vital ingredient to the success of emerging NAVSEA robotics programs is a solid 6.1 and 6.2 effort prior to initiating 6.3 level development. This has not been the experience to date. During Robotics Committee technical reviews, it became apparent that certain projects were failing to meet design goals due to the existence of technology voids unidentified early in the process. This resulted in false starts requiring redirection, and in some cases, cancellation of ongoing efforts.

In those cases where it becomes necessary to phase down a project, it is wise to develop a lessons learned package, even though it is possible that the findings are negative. Also, where economy is required, scheduling and prioritization are essential in order that slack time can be put to productive use.

These observations underscore the need to articulate common goals and objectives, develop the knowledge base, utilize resources such as the Robotics Committee and RAID, and maximize technology transfer.

LESSONS LEARNED

- COMMUNICATION IS ESSENTIAL TO THE DEVELOPMENT PROCESS
- UNDERSTANDING OF ROBOTIC CAPABILITIES AND APPRECIATION OF TECHNOLOGY DEFICIENCIES IS IMPORTANT
- PRIVATE INDUSTRY WILL NOT MEET ALL NAVY NEEDS
- RESEARCH AND EXPLORATORY DEVELOPMENT REQUIRED:
    - TO AVOID FALSE STARTS
    - SOLID 6.1 AND 6.2 EFFORTS MUST PRECEDE 6.3 PROJECTS
- PROJECT MANAGER INVOLVEMENT:
    - KNOWLEDGE OF ROBOTIC TECHNOLOGY NECESSARY
    - PARTICIPATION IN PLANNING AND ASSESSMENT REQUIRED
- TECHNOLOGY TRANSFER ESSENTIAL IN LIGHT OF LIMITED RESOURCES

SUMMARY, CONCLUSIONS AND PROJECTIONS

APPLICATION/TECHNOLOGY MISMATCH CONCERNS

To achieve effective application of robotics technology, it is necessary to first raise the overall level of understanding and awareness of available technological capabilities. The development of the technology baseline is, therefore, an important first step in the process. Establishment of a technology baseline at the beginning of the program would facilitate the process of assessing the effectiveness of certain technologies in proposed applications.

Deficiencies in supporting technology will impede, if not preclude, successful implementation of robotic solutions. The challenge is to keep existing projects from overreaching, while building up a well developed robotic technology baseline. The assessment and review of ongoing projects will continue in order to ensure that design goals can be met with available technology. At the same time, the increased base of knowledge of potential applications and development of required technologies must be continually balanced.

The growth of technology continues to accelerate. Timely and appropriate steps must be taken to ensure that available robotic technology is employed, while avoiding false starts on projects requiring as yet unproven technologies. Greater application of the existing robotics planning approach (page 6) will support identification and utilization of appropriate technology.

Once candidate projects have been selected from the potential population, the measure of effectiveness for specific applications must be determined. Development and use of appropriate cost models, understanding of system needs, and the requirement for compatibility and standardization are all important factors in the equation. Additional concerns include the impact on training, manning levels, at-sea concept validation, and mission readiness.

In the near term, it is essential that attention be focused on the implications of adopting robotic technology on policy, program structure, operations, R&D, manpower, training and supply support. Communicating the policy regarding the robotics technology thrust at NAVSEA, coupled with the need to provide an active technology transfer and support service beneficial to both NAVSEA functional codes and the research community, is important to the ultimate implementation of potential applications. Further, steps to ensure long-range viability of the program include a commitment to securing support for talent, research studies and operations, as well as expanding program activity into such areas as intermediate and depot level repair, which account for a significant portion of system life cycle cost.

APPLICATION/TECHNOLOGY MISMATCH CONCERNS

- EARLY DEVELOPMENT OF ROBOTICS TECHNOLOGY BASELINE CONTRIBUTES TO:
  - INCREASED AWARENESS OF TECHNOLOGICAL CAPABILITIES
  - EFFECTIVE APPLICATION OF ROBOTICS TECHNOLOGY
  - UNDERSTANDING OF SYSTEM INTEGRATION NEEDS
  - PROMOTING COMPATIBILITY/STANDARDIZATION

- CONCERNS:
  - ROBOTIC TECHNOLOGY BASELINE NOT FULLY DEVELOPED
  - TECHNOLOGY DEFICIENCIES MAY IMPEDE TIMELY AND EFFECTIVE IMPLEMENTATION RESULTING IN FALSE STARTS
  - LACK OF AWARENESS MAY RESULT IN INAPPROPRIATE APPLICATION
  - ABILITY TO COPE WITH EXPANDING ACTIVITY IN NEW AREAS SUCH AS INTERMEDIATE AND DEPOT LEVEL REPAIR

- NECESSARY TO UNDERSTAND IMPLICATIONS OF ROBOTICS TECHNOLOGY APPLICATIONS ON:
  - POLICY
  - PROGRAM STRUCTURE
  - FUNDING
  - OPERATIONS
  - MANPOWER
  - TRAINING
  - SUPPLY SUPPORT

PROGNOSIS: SHIPBUILDING AND WEAPONS MANUFACTURING

Shipbuilding and weapons manufacturing offer a fertile field for the introduction of robotic technology into various processes, but such a transition to flexible automation will not occur overnight. This is due primarily to the low manufacturing volumes and associated unstructured environments encountered in ship construction, and the lack of production-ready sensor and adaptive control technology to resolve these issues. Nevertheless, efforts are underway to pursue those applications most favorable for near-term development, to include material handling, sheet metal fabrication, cutting of structural components, parts positioning, and welding. Other developments are aimed at automating various machining operations, surface preparation and painting, and noncontact inspection and measurement.

Much of the above work has addressed robotic welding because previous applications studies showed this to be the most productive area for short-term investment. The inability of commercially available robotic welding systems to adapt to variations in joint geometry brought on by thermal expansion, poor initial fit-up, or other variables associated with the welding process, has impeded their cost-effective use by the Navy. The long-term intent therefore of MT-funded robotic developments in NAVSEA has been to provide to such systems the sensory feedback needed to increase their level of intelligence and to allow them to function in an adaptive fashion under changing conditions.

The building of warships is perhaps the most complex task undertaken by any industrial enterprise anywhere in the world. It involves the design, construction, installation, and testing of sophisticated weapons systems, sensor systems, and a vast number of supporting environmental control and operating subsystems within enormous steel structures which offer only limited physical access. Shipbuilding tasks are basically one-of-a-kind production operations in a uniquely unstructured environment. Hence the implementation of robotics technology is many times more difficult than in other industries with high volume, repetitive assembly line characteristics.

Two things are happening, however, which collectively will facilitate the eventual use of flexible automation in shipbuilding. Manufacturers and systems developers are now turning their attention to that portion of the market that requires some type of adaptive control for robotic solutions to be effective. With this increased level of attention, numerous forms of process sensors, vision systems, and schemes for workcell and factory automation are evolving. At the same time, the implementation on the part of the shipyards of group technology concepts will ease the introduction of this intelligent automation into tasks that were heretofore deemed impossible, in that lot sizes will increase and environments will become more structured.

PROGNOSIS:
SHIPBUILDING AND WEAPONS MANUFACTURING

- HIGH PAYOFF AND LOWEST RISK

- ADAPTIVE WELDING, SURFACE PREPARATION AND PAINTING, CLEANING, CUTTING ARE DOABLE NOW AT MINIMUM RISK:

  - COSTS COMING INTO RANGE
  - SUPPORTING CAD NOW AVAILABLE
  - MAJOR NAVY EFFORTS UNDERWAY

- PAYOFF:

  - REDUCED COST
  - DECREASED PRODUCTION TIME
  - INCREASED FLEXIBILITY IN DESIGN CHANGES
  - IMPROVED QUALITY
  - IMPROVED INDUSTRIAL PREPAREDNESS
  - IMPROVED WORKING CONDITIONS

PROGNOSIS: REPAIR AND MAINTENANCE

The majority of industrial robotic development activity to date by NAVSEA has addressed applications in shipbuilding and weapons manufacturing as opposed to repair and refurbishment, primarily due to the more structured nature of larger volume operations. A significant share of the life cycle costs of a weapons system, however, is directly attributable to the repair and maintenance needs over an extended period -- often greater than 20 years. Rising costs, and the subsequent retrenchment of the shipbuilding and repair industry, has led to concerns in the Navy today as to whether the U.S. will be able to respond to the surge demands which accompany emergency situations. Increased emphasis may be placed on our ability to quickly respond to requirements for rapid repair, and flexible automation is seen as offering a growing potential to improve capabilities in this area.

Repair functions at naval shipyards typically involve non-repetitive processes that heretofore were not practical as potential robotic candidates, in that the time required to program the system could not be amortized over a series of identical parts. Similar conditions prevail in the depot-level refurbishment operations performed at Naval Weapons Stations, although the number of repetitive items generally is greater. The development of intelligent systems which rely upon sensor feedback to provide adaptive control has opened up new areas of involvement, allowing practical implementation in low-volume, unstructured environments to indeed become an achievable reality.

Looking back on the technological advances made in just the past five years, it is reasonable to assume that robotic systems will play a significant role in repair and refurbishment operations in the not-too-distant future. An important consideration, therefore, must be to ensure that ships and weapons systems which will be introduced to the fleet in the next 10-15 years are designed with automation in mind. There is great opportunity for the eventual integration of advanced technologies into modernized repair and maintenance activities at both the intermediate and depot level, but the ship systems must be compatible with the projected repair capabilities. Design-for-automation issues such as standardization of fasteners and even subcomponents become very important.

Appropriate application of flexible automation could very well result in dramatic reductions in repair and overhaul costs. While the technical risks are somewhat greater than for shipbuilding and manufacturing scenarios, so also are the long-term potential payoffs. Maintenance and repair requirements will continue to grow long after the 600-ship Navy is realized, and it is essential that innovative solutions be developed and exploited to provide an ability to maintain a high state of fleet readiness. The eventual integration of expert systems designed as training, diagnostic, and decision aids will further extend capabilities, broadening the range of potential applications while reducing the need for sophisticated training and skills.

PROGNOSIS:
REPAIR AND MAINTENANCE

- HIGHEST PAYOFF AND MEDIUM RISK
- INCREASING USE OF CAD DATA, SENSOR FEEDBACK, AND IMPROVED PROGRAMMING TECHNIQUES MAKING INDUSTRIAL ROBOTS MORE PRACTICAL FOR SMALL REPAIR JOBS
- INTEGRATION WITH EXPERT SYSTEMS WILL EXTEND CAPABILITY
- SIGNIFICANT SUCCESSES SHOULD BE EXPECTED IN 5-10 YEARS
- PAYOFF:
    - IMPROVED INDUSTRIAL PREPAREDNESS
    - HIGHER PRODUCTIVITY
    - IMPROVED WORKING CONDITIONS
    - HIGHER QUALITY
    - REDUCED TRAINING/SKILLS REQUIREMENTS
    - MORE COMPLEX REPAIR CAPABILITY
    - REDUCED MANPOWER

PROGNOSIS: OPERATIONS/OPERATIONS SUPPORT

The list of operational scenarios involving robotic technology continues to grow, while the prospects for their broad application remain somewhat uncertain. The unstructured environments in which these proposed automated systems must operate include shipboard, underwater and airborne applications. Problems arise when such systems become too complex, or perform unreliably at critical times.

Up to now, successful application of shipboard automation has been limited primarily to combat systems. The prescribed intent has been to increase performance and reduce manning requirements of naval combatants, while maintaining a safe and effective fighting platform. Failure of a critical component, however, can quickly negate any corresponding manpower savings. In fact, experience to date has shown that in many cases involving shipboard automation, projected manpower savings have not been fully realized due to problems with system reliability.

The greater the degree of automation employed, the greater the need for highly trained personnel, in that maintenance and repair requirements usually increase. Significant advances in artificial intelligence are being investigated for their potential to alleviate some of these problems. Before long, use of expert systems as troubleshooting tools and training aids will be commonplace.

Successful adaptation of robotic technology depends heavily on the severity of the operational environment. Hazardous duty functions involving tethered or semi-autonomous platforms operating on land or undersea have generated much interest. Applications include explosive ordnance disposal, NBC detection and decontamination, and mine placement and neutralization. Projected systems show some potential for improving unit effectiveness and safety, with limited damage resulting from system failure.

In summary, application of robotics technology to certain Navy operational functions can result in significant productivity improvement, and reduce exposure of personnel to hazardous environments. Dangerous, mundane or repetitive operational tasks are prime potential candidates for automation. Before widespread acceptance is possible, however, problems associated with system reliability, maintainability, and training will have to be solved. Impact on manning levels and skills requirements is not at all clear and must be further assessed; any resulting reduction in manpower may well be accompanied by a significant increase in associated skills for operation and maintenance. Another factor to consider, even with proven system reliability, is the recognition that traditional Navy manning levels are dictated by the manpower needs required during increased readiness conditions, which may very well prove to be the dominant issue from an overall perspective.

PROGNOSIS:
OPERATIONS/OPERATIONS SUPPORT

- POTENTIAL HIGH PAYOFF BUT HIGHEST RISK

- UNSTRUCTURED ENVIRONMENT MAKES THIS THE MOST DIFFICULT PROBLEM

- INITIAL AREAS OF INVESTIGATION TO INCLUDE:
  - UNDERWATER SEARCH
  - EXPLOSIVE ORDNANCE DISPOSAL
  - MUNITIONS HANDLING
  - NBC DEFENSE
  - MINE PLACEMENT/NEUTRALIZATION

- ANY RESULTING REDUCTION IN MANNING MAY BE MATCHED BY INCREASED MAINTENANCE REQUIREMENTS (IN THE SHORT TERM)

- SIGNIFICANT SUCCESSES SHOULD BE EXPECTED IN 10-15 YEARS

- PAYOFF:
  - REDUCED MANNING POTENTIAL
  - REDUCTION IN NET TRAINING REQUIREMENTS
  - BETTER WORKING CONDITIONS
  - IMPROVED QUALITY/PERFORMANCE
  - SAFETY ISSUES
  - IMPROVED SURVIVABILITY

FY 86 PLANNING OBJECTIVES

In FY 86, the Office of Robotics and Autonomous Systems will pursue objectives in a way that balances programmatic and technical interests. Thematically, the approach will be to develop the program in a steady, consistent manner that will reflect good management practices, establish accountability at both the project level and the program level for achieving results, and coordinate/prioritize/expedite research toward early, incremental payoff as an encouragement for further investment in the development of componentry for robotics applications.

The first step in this process is to confirm by inspection, analysis, and experience that the Program Plan -- consisting of an overall goal, three subgoals, a set of program and project objectives, and a structured approach (as set forth in Section I) -- remains a viable vehicle for responding to lessons learned. All indicators, including independent outside analyses such as that provided by the Naval Studies Board, are that the merits of the plan are many, and that the existing problems are not of a planning nature.

The rapid growth in the number of projects (Section II) has seriously over-taxed the resources of the Office of Robotics and Autonomous Systems. The need to remedy this situation is reflected in both near-term and out-year planning. In FY 86, it will be necessary to improve the Annual Operating Plan (AOP) which is the mechanism by which work is specified and ranked by priority. The overload of work can also be addressed through the formalization of the Robotics Committee. Its effectiveness, in turn, can be maximized by providing a coherent process for conducting project reviews, and developing a package of tools permitting the Committee to render consistent, uniform, and objective technical recommendations.

The project that best exemplifies the spirit and intent of the Robotics Program is the Integrated Flexible Welding System (IFWS), the featured presentation at the CAD/CAM Mini-Symposium of the Manufacturing Technology Advisory Group (MTAG). In the remainder of the year, it will gain further attention through two technology demonstrations of its principal components, and plans will be completed for implementing an early, interim system configuration. This implementation, planned for Puget Sound Naval Shipyard, is expected to have payoff potential during the time required to complete further research to make the system fully adaptable to the production environment that characterize shipyard endeavors. As the major undertaking in the NAVSEA program, the IFWS project is expected to contribute valuable lessons and specific technology that can be adapted in other projects.

FY 86 PLANNING OBJECTIVES

- SYSTEM OBJECTIVE: TO REVIEW, CONFIRM, OR MODIFY THE PROGRAM PLANNING CONCEPT, APPROACH, AND GOAL/SUBGOALS/OBJECTIVES STRUCTURE

- KEY PROGRAMMATIC OBJECTIVES:

  - TO DEVELOP, PROMULGATE, AND MONITOR THE EXECUTION OF THE FY 86 ANNUAL OPERATING PLAN

  - TO COMPLETE THE FORMALIZATION AND INSTITUTIONALIZATION OF THE ROBOTICS COMMITTEE

  - TO DEVELOP THE "TOOLS" REQUIRED BY THE ROBOTICS COMMITTEE TO EFFICIENTLY AND SYSTEMATICALLY CARRY OUT THE SCOPE OF ITS CHARTER

  - TO ESTABLISH THE INTEGRATED FLEXIBLE WELDING SYSTEM AS THE TECHNOLOGICAL FORERUNNER FOR THE NAVSEA INTEGRATED ROBOTICS PROGRAM

  - TO DEMONSTRATE THE NEED FOR SIGNIFICANTLY INCREASING THE 6.1 AND 6.2 TECHNOLOGY BASE DEVELOPMENT EFFORTS IN SUPPORT OF ROBOTICS TECHNOLOGY FOR NAVY-UNIQUE NEEDS

  - TO INITIATE THE INVESTIGATORY AND COMMAND AWARENESS ACTIONS THAT WILL PRODUCE A "BANK" OF VALIDATED FLEET OPERATIONAL SUPPORT APPLICATIONS

  - TO DEVELOP THE CONSORTIUM APPROACH FOR SHARING THE TECHNICAL SKILLS RESIDENT IN SOME BUT NOT DUPLICATED IN ALL OF THE NAVY SUPPORT CENTERS

FY 86 PLANNING OBJECTIVES (Continued)

The successfully completed project reviews conducted in the past year have demonstrated that the Navy's industrial robotic needs have outpaced the development of the required technology base. Further investigation has revealed that the current technology base research is significantly unbalanced, with artificial intelligence being much more thoroughly pursued than general robotics technology. In FY 86, efforts will be made to promote a better balanced program, increasing the overall effort in support of robotics, so that the results can be used to support engineering development work in the out years. In the intervening period, concentration will continue on utilizing the "requirements pull" approach to establish a bank of approved applications that can be matched to the available technology in a manner that will ensure that engineering development efforts will essentially be limited to pay-off opportunities.

The common ground for integration activity resides in the Robotics/Artificial Intelligence Database (RAID). With the data collection, recording, retrieval, and communications elements of the RAID process in place, tested and working, concentration in FY 86 will be on achieving greater utilization of the wealth of data that has been accumulated. This objective will be sought through direct solicitation of additional users who may not currently be aware of the available service. Additionally RAID services will be made more readily recognizable by developing concise technological abstracts of each project so that a single, quick reading can advise a project investigator whether or not another project may be able to provide technological data in support of his project.

FY 86 PLANNING OBJECTIVES (CONTINUED)

- SELECTED PROJECT OBJECTIVES:

  - TO CONDUCT TWO OR MORE DEMONSTRATIONS OF PROMISING TECHNOLOGICAL DEVELOPMENTS THAT CAN BE IDENTIFIED FOR ADAPTATION TO ONE OR MORE NAVY APPLICATIONS

  - TO INCREASE BY 50 PERCENT THE NUMBER OF COMPREHENSIVE PROJECT REVIEWS TO UNCOVER TECHNOLOGY TRANSFER OPPORTUNITIES AND TO IDENTIFY, ASSESS, AND CLASSIFY TECHNOLOGY DEFICIENCIES AND VOIDS

  - TO INCREASE BY 100 PERCENT THE UTILIZATION OF THE ROBOTICS/ARTIFICIAL INTELLIGENCE DATABASE (RAID), AND EXPAND ITS CAPABILITY THROUGH MODIFICATIONS TO PROVIDE CONCISE TECHNOLOGICAL ABSTRACTS THAT WILL INCLUDE:
    - -- TECHNOLOGY ADVANCES SOUGHT
    - -- TECHNOLOGY ADVANCES GAINED
    - -- A MEASUREMENT OF DIFFERENCE BETWEEN EXPECTATIONS AND ACHIEVEMENTS
    - -- AN ANALYTICAL "LESSONS LEARNED" SUMMARY

OUT-YEAR PLANNING INITIATIVES

With three years of experience on which to base its longer-range planning, the Office of Robotics and Autonomous Systems is well postured to complement its successful oversight management of its many projects with initiatives that will greatly increase its ability to effect the technical coordination required to bring projects to readiness for prototype development or pre-implementation analyses and decisions.

True long-range planning is still not feasible for the reasons explained in the Program Status and Prognosis; it is possible and appropriate, however, to extend the planning horizon beyond that which has heretofore been limited to remedial actions taken to integrate independently originated projects to the broader Program Objectives. The requisite planning tools for transitioning from reaction planning to near-term planning, and ultimately to long-term planning, are described in the following segment on The Planning Mechanisms.

Organizationally, one of the key initiatives for ensuring the success of the Robotics Program is to increase the resources available to the program manager. Additional personnel are required in SEA 90G, particularly on the technology side of the house, where the major need is for an assistant to assume responsibility for technology transfer activities. In this role, the assistant would be able also to address attention to the Command Awareness sub-goal (Section I), and initiate a set of actions to greatly enlarge the Navy constituency of decision makers who are aware of both the potential and limitations of robotics technology.

Additional assistance from external sources is contemplated through the completion of a laboratory consortium arrangement by which scarce technical resources will be shared on a project-by-project basis. In its initial configuration, this consortium will be limited to the facilities that are located in the Washington, D.C. area; as the capability for long-range planning improves, it is conceivable that the consortium notion could be extended to the remote centers. It is clear at this time that no laboratory or center will be -- or can expect to be -- expertly staffed to address all the component technologies required by robotics applications. Sharing, and the prioritization/scheduling of effort, is the only practical solution. For this to be efficient and effective, the planning mechanisms will have to be exercised extensively and fine-tuned appropriately, as experience dictates.

OUT-YEAR PLANNING INITIATIVES

- ORGANIZATIONAL DEVELOPMENTS IN THE NAVSEA OFFICE OF ROBOTICS AND AUTONOMOUS SYSTEMS
- PROGRESSIVE EXTENSION TO A BROADER NAVY CONSTITUENCY
- GREATER USE, WITH FINE TUNING, OF THE APPROVED BUT LARGELY DORMANT ROBOTICS PLANNING MECHANISM
- OPERATIONAL STATUS FOR THE LABORATORY/CENTER CONSORTIUM FOR SHARING SCARCE TECHNOLOGY-DEVELOPMENT RESOURCES
- CONCEPTUAL DEVELOPMENT OF THE NOTION OF MANPOWER LIMITATIONS (IN NUMBERS AND SKILLS) AS THE PRIME DRIVER FOR ACCELERATING THE ROBOTICS PROGRAM
- PROMOTE PROMPT AND FULL PARTICIPATION OF THE JOINT TECHNICAL PANEL FOR ROBOTICS IN PERFORMING ALL RESPONSIBILITIES ASSIGNED BY THEIR CHARTER

OUT-YEAR PLANNING INITIATIVES (Continued)

Early in the out years, it will be necessary to build the case that the ultimate program driver will be manpower -- not just productivity, safety, or relief from boring, mundane labor. Similarly, our out-year planning includes an initiative to assist the Joint Technology Panel for Robotics (JTPR) to perform effectively in all the responsibilities assigned in their Charter, as prescribed by the Joint Directors of Laboratories. This effort will ensure that the Navy's interests are fully considered in the preparation of the Joint Director's Five-Year Plan for the development of robotics technology.

As out-year planning proceeds on the course sketched out above, the role of the newly chartered Robotics Committee will become more dominant in program guidance decisions. The Committee will be scheduled more aggressively to conduct rigorous project reviews and to assist project managers to surmount technical hurdles impeding progress. Use of the new tools at appropriate times in a consistent manner will greatly increase the capability of the Committee to make prompt and accurate assessments, to extrapolate knowledge gained in one project to the benefit of other projects, and in the process, to measurably improve the Committee's credibility.

The greatest challenge to the out-year planning process is to overcome the funding shortfalls that have inhibited the rate of progress that could be achieved in developing or acquiring technology for Navy-unique needs. The first initiative will be to overcome the anomalies in control procedures that effectively say that RDT&E funds must go to approved projects (not studies) while withholding O&MN funding to do such studies that would make possible the identification of worthwhile (cost effective and technically feasible) projects that would then qualify for RDT&E funding support.

OUT-YEAR PLANNING INITIATIVES (CONTINUED)

- PROMPT AND CONSISTENT USE BY THE ROBOTICS COMMITTEE IN THE EFFECTIVE APPLICATION IN PROJECT REVIEWS OF THE:
  - COST/BENEFIT ANALYSIS MODEL
  - TECHNOLOGY ASSESSMENT PROCEDURE
  - TECHNOLOGY TRANSFER MECHANISM
  - MANPOWER IMPLICATION ANALYSIS MODEL

- RESOLUTION OF FUNDING OBJECTIVE SHORTFALLS BY ENSURING:
  - O&MN FUNDING TO SATISFY PROGRAM REQUIRING FOR:
    - TECHNOLOGY ASSESSMENT STUDIES
    - APPLICATION ANALYSIS AND FEASIBILITY REVIEWS
    - ROBOTICS COMMITTEE SUPPORT
    - COST BENEFIT ANALYSIS MODEL DEVELOPMENT/REFINEMENT
    - MANPOWER IMPLICATION MODEL
    - RAID ENHANCEMENT AND SUPPORT
  - RESEARCH, DEVELOPMENT AND TESTING FUNDING TO:
    - ESTABLISH A SOLID 6.1, 6.2 ROBOTICS TECHNOLOGY BASE
    - PROVIDE FOR INTERACTION WITH AND BETWEEN NAVY SUPPORT CENTERS
    - FACILITATE TECHNOLOGY TRANSFER

THE PLANNING MECHANISMS

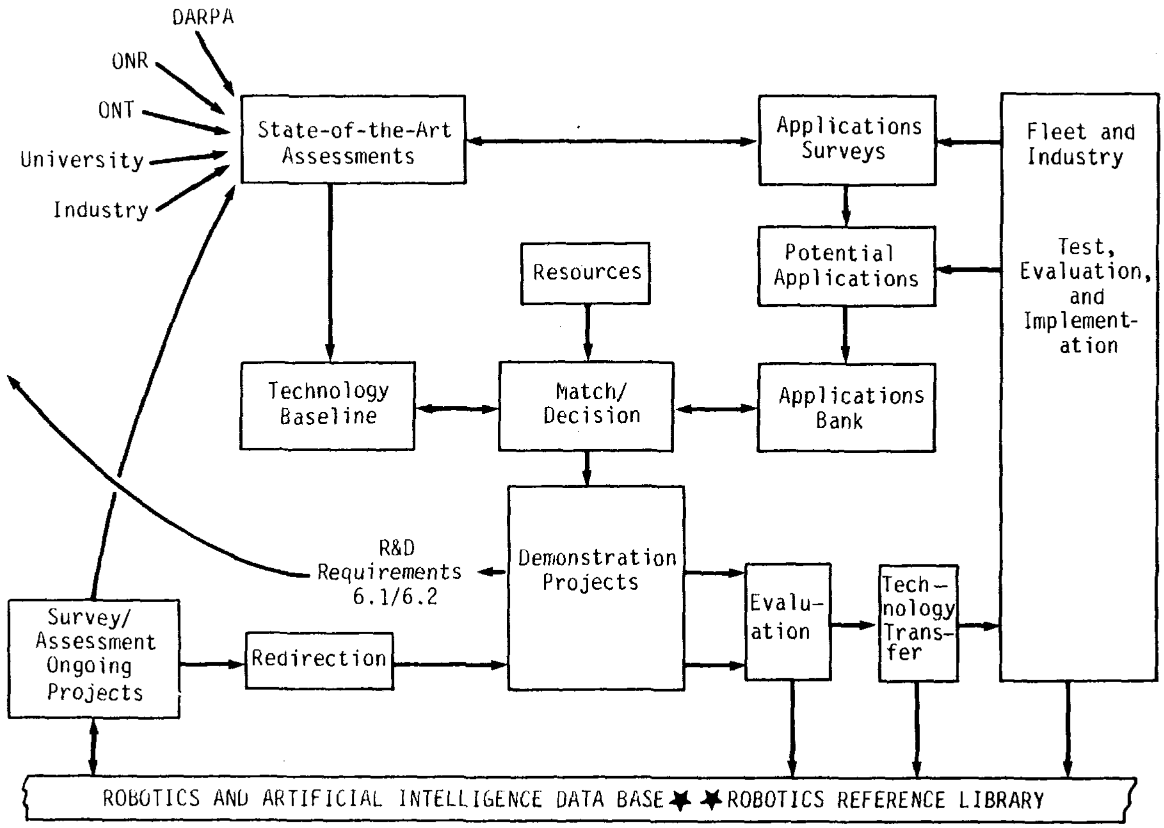
The Technology Development Model

The Structured Program of Technology Assessment, Applications Studies, Focused R&D, and Demonstration Projects, illustrated on the facing page, shows the interrelationships between all functions for which the Office of Robotics and Autonomous Systems -- with active participation of the Robotics Committee -- maintains oversight and effects coordination. This structured program results in the incorporation of robotic technology into Navy shipbuilding and weapons manufacturing, repair, and operational applications.

Because of the highly generic nature of technology (and the premise that projects could benefit from cross fertilization) and diverse nature of applications, this program features centralized policy direction, decentralized execution of individual projects, and close coordination. This approach requires and stresses the development and maintenance of a shared technology baseline defining both the capabilities and limitations of the technology, and an application baseline that defines when and where robotics can be applied successfully in the Navy. Applications of the structured program in assessing ongoing projects were made during FY 85. As an example, an assessment of the Robot Assisted Surface Preparation and Paint (RASPP) Project was performed by the Robotics Committee and the determination was made that technical feasibility had not been demonstrated, resulting in a redirection of the effort.

There is no fixed entry point for the model outlined in the illustration. Application of the model may begin with the survey and assessment of an ongoing project (which is characteristic of the current level of activity in the Robotics Program), a technology transfer action, a user requirement, or other activity. Once the model is applied, however, the flow continues, and the application, assessment, or project being considered is subjected to as many focused looks and iterations as are required to lead to a conclusion -- implementation, redirection, or possibly the identification of a technology void. Given the resources necessary to implement the model, the findings that result may be the matching of a desired application to an existing technology, or the discovery of a technology that, through the process of innovation, can be applied to a previously unappreciated need.

A STRUCTURED PROGRAM OF TECHNOLOGY ASSESSMENT, APPLICATIONS STUDIES, FOCUSED R&D, AND DEMONSTRATION PROJECTS



THE PLANNING MECHANISMS

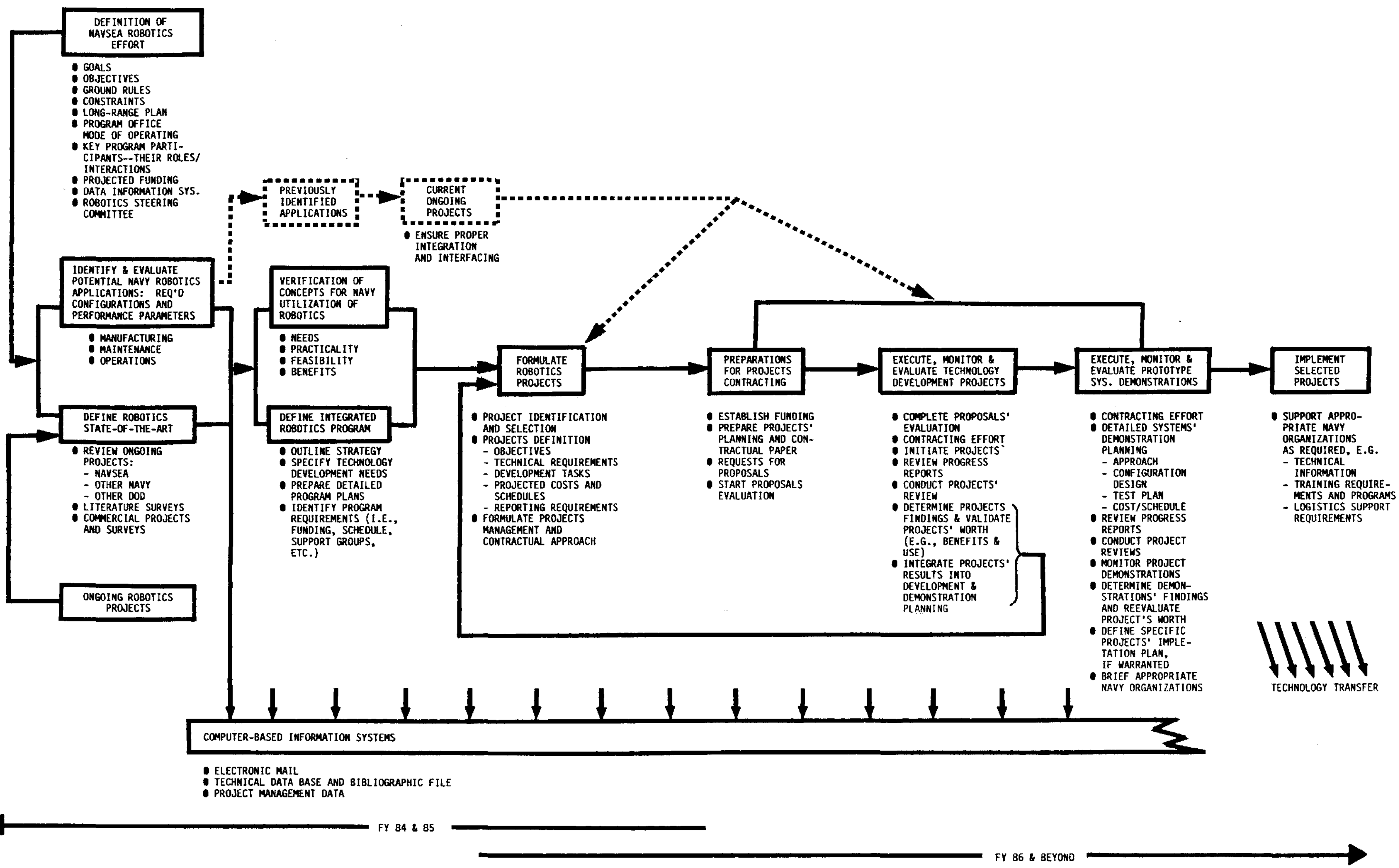
The Planning Scenario

The Robotics Planning Scenario adds time and functional detail to the closed-loop approach sketched in the first illustration, and spawns the Annual Operating Plan (AOP), which, for a given year, sets forth a definitive schedule of actions to be undertaken or completed. The illustration shows the great degree of interactivity required in the planning process. The importance of accurate and timely input, open communications, and feedback to the successful development and implementation cannot be overemphasized.

The Project Integration Matrix

The Project Integration Matrix lists the industrial and non-industrial projects that comprise the NAVSEA Integrated Robotics Program as described in Section II. The matrix shows the diverse nature of the related projects within NAVSEA. Project management originates from a variety of NAVSEA Codes and involves a broad range of participants from government and private industry. The projects, representing the growing thrust of the NAVSEA Robotics Program, are all at various stages in the planning scenario. The compilation includes over fifteen functional areas within the general categories of Shipbuilding and Weapons Manufacturing, Repair and Maintenance, and Operations.

ROBOTICS PLANNING SCENARIO



THE PROJECT INTEGRATION MATRIX
INDUSTRIAL APPLICATIONS

FUNCTIONAL AREA	PROJECT NAME/AREA	NAVSEA CODE		PROJECT MANAGER		PERFORMING ORGANIZATION	ANNUAL REPORT PG
WELDING – GMAW	ICI Architecture	90G	Bart Everett	NOSC	Scott Harmon	NOSC	20
	Offline Programming	90G	Bart Everett	ONR	Alan Meyrowitz	Carnegie Mellon Univ	
	Global Vision System	90G	Bart Everett	NSWC	Jon Moscar	Associates and Ferren	24,26
	3D Seam-tracking (3D-WSTS)	070A	Roy Wells	070A	Roy Wells	Robotic Vision Systems	28
	Robotic Adaptive Welding System	070A	Roy Wells	070A	Roy Wells	Westinghouse	32
	Oxford Robotic Welding Sys Eval	90G	Bart Everett	ARL	Henry Watson	Penn State University	
	Robotic Weld In-Process Control	05R25	Ivan Caplan	DTNSRDC	Abe Pollack	DTNSRDC	
	Ultrasonic Imaging	90G	Bart Everett	DTNSRDC	Bob Jenkins	Idaho Nat Eng Lab	
	Catapult Cover Refurbishment	070A	Roy Wells	T.B.D.	T.B.D.	T.B.D.	62
	Sheet Metal Welding System	070A	Roy Wells	T.B.D.	T.B.D.	T.B.D.	64
WELDING – LASER	Laser Articulating Robotic Sys	06L1	Garth Brown	ARL	Henry Watson	NIROP/MTS Systems	34
WELDING – QA	Automated Fusion-Weld Inspection	06L1	Garth Brown	NOSC	Rick Davidson	General Dynamics/Convair	46
METAL WORKING	Automated Mfg Research Facility	06L1	Garth Brown	NBS	Phil Nanzetta	Nat Bureau of Standards	58
	Robotic Structural Shapes Proc	05R43	John Freund	DTNSRDC	Bob Jenkins	Bath Iron Works	48
	Automated Thermal Spray Workcell	070A	Roy Wells	PSNS	Frank Rogers	T.B.D.	66
	IMA Automated Work Centers	56X52	Myron Powell	56X52	Myron Powell	T.B.D.	136
COMPOSITES	Comp Hull Adv Manf Process(CHAMP)	55Y13	Tom Gallagher	55Y13	Tom Gallagher	CASDE Corporation	52
PROPELLER MANUFACTURING	Integrated CAM of Props(ICAMP)						
	-Prop Auto Welding Sys (PAWS)	070A	Roy Wells	070A	Roy Wells	Robotic Vision Systems	50
	-Prop Optical Finishing System	070A	Roy Wells	070A	Roy Wells	Robotic Vision Systems	50
	-Propeller Balancing (PROBAL)	070A	Roy Wells	070A	Roy Wells	Robotic Vision Systems	50
	-Auto Prop Optical Meas (APOMS)	070A	Roy Wells	070A	Roy Wells	Robotic Vision Systems	50
MEASUREMENT	Intelligent Robotic Inspect Sys	06L1	Garth Brown	ARL	Henry Watson	MTS Systems	42
	Ships Surface Scanner Program	070A	Roy Wells	070A	Roy Wells	Robotic Vision Systems	70
SURFACE PREPARATION	Robot Assist Surf Prep & Paint	05R43	John Freund	NAVSSES	Ken Eager	Ingalls Shipbuilding	56
	Trident Hull Prep	0703A	Ed Worff	0703A	Ed Worff	Wheelobrater Frye	54
ORDNANCE	Assembly/Disassembly Workstation	0613C	H. Peesel	Ind Head	Peter Margiotta	NAVORDSTA-Ind Head	72
	Residual Magnetism Workstation	0613C	H. Peesel	Ind Head	Brian Aunkst	NAVORDSTA-Ind Head	72
	Parts Loading Robot	0613C	H. Peesel	Ind Head	Chuck Miller	NAVORDSTA-Ind Head	72
	Thread Chasing Robotic System	0613C	H. Peesel	Ind Head	Glenn Campbell	T.B.D.	72
	Robotic Vision Inspection System	0613C	H. Peesel	Ind Head	Eugene Stefko	T.B.D.	74
	MK-27 Fuze Inspection System	0613C	H. Peesel	Concord	J. Prindville	T.B.D.	76
	IR Test System	0613C	H. Peesel	Crane	Jack Kramer	T.B.D.	76
MATERIALS HANDLING	Ammo Offloading & Inspection Sys	0613C	H. Peesel	Crane	T.B.D.	T.B.D.	68
	Mobile Robot for Nuclear Ops	070A	Roy Wells	MINS	T.B.D.	T.B.D.	

THE PROJECT INTEGRATION MATRIX (CONTINUED)

NON-INDUSTRIAL APPLICATIONS

FUNCTIONAL AREA	PROJECT NAME/AREA	NAVSEA CODE		PROJECT MANAGER		PERFORMING ORGANIZATION	ANNUAL REPORT PG
	ROVER	06G6	CDR Stan Denham	NEODTC	John Butler	Foster Miller Inc	80
	Remote Interface Concepts	06G6	CDR Stan Denham	NEODTC	John Butler	Engineering Technology Inc	84
	SAMSON	06G6	CDR Stan Denham	NEODTC	John Butler	T.B.D.	82
	ReCoRM	06G6	CDR Stan Denham	NEODTC	John Butler	T.B.D.	82
	ROME	06G6	CDR Stan Denham	NEODTC	John Butler	Battelle Columbus	86
	HERC	06G6	CDR Stan Denham	NEODTC	John Butler	Foster Miller	88
EXPLOSIVE ORDNANCE DISPOSAL	English Language ROBCOM	06G6	CDR Stan Denham	NEODTC	John Butler	George Washington Univ	90
	3D Vision-Human Operators	06G6	CDR Stan Denham	NEODTC	John Butler	Honeywell	90
	Guided Robotic Disassembly Sys	06G6	CDR Stan Denham	NEODTC	John Butler	Univ of Texas at Austin	92
	Surface/Subsurface Clearance Veh			NEODTC	John Butler	T.B.D.	94
	Borehole Location/Detection Sys			NEODTC	John Butler	T.B.D.	94
	ADROV	06G6	LCDR C. Bernier	NEODTC	John Pennella	Hydro Products	96
	Pluto Evaluation	06G6	CDR Stan Denham	NEODTC	John Pennella	Westinghouse/Gaymarine	98
	Deep Drone	00C	Tom Salmon	00C	Tom Salmon	Eastport International	100
UNDERWATER SERVICES	Deep Submergence Manipulators	PMS395	Don Johnson	PMS395	Don Johnson	Mare Island Naval Ship Yd	100
	Autonomous UW Vehicle	05R43	John Freund	NOSC	I. Lemaire	NOSC	
	Advanced Tethered Vehicle	05R43	John Freund	NOSC(H)	Terry Hoffman	T.B.D.	100
	Undersea Search Vehicle	05R43	John Freund	NOSC	Norm Estabrook	NOSC	100
	Robotic Hull Inspection System	05R12B	Fred Saxton	NOSC(H)	Ross Pepper	SEACO Inc	102
FIRE FIGHTING	Remote Control Fire Fighter	56D5	Wade Webster	NSWC	Mary Lacey	NSWC R402	104
SECURITY	Waterside Security System	06G3	Leo Targosz	06G3	Leo Targosz	NOSC	106
	Nuclear Facility Security	6432	John Lally	DNA	Bill Witter	Meridian/Odetics/SAIC	108
BIOLOGICAL AND CHEMICAL DEFENSE	Chem & Biological Survey	05R16	John Guarino	05R16	John Guarino	SESCO	131
	Sensor Survey	90G	Bart Everett	90G2	Mick Flowers	NSWC	130
	Autonomous Mobile Robot (ROBART)	90G	Bart Everett	NSWC	Anita Flynn	MIT AI Lab	112
	Robotics/AI Database (RAID)	90G	Bart Everett	NOSC	Dick Gamble	Computer Sciences Corp	116
GENERIC DEVELOPMENTS	Active 3D Vision	90G	Bart Everett	ONR	Alan Meyrowitz	Case Western Reserve Univ	122
	Robotic Micromanipulator	90G	Bart Everett	NBS	Phil Nanzetta	Univ of Texas at Austin	60
	Joint Tech Panel for Robotics	90G	Bart Everett	90G	Bart Everett		120
	Technology Overview of Intel Sys	PMS309	Russ Ruppert	SEAADSA	Robert Boykin	SEAADSA	124
	Shipboard Application Study	05R14	Charles Lawson	NSWC	Sharon Hogge	NSWC/SESCO	
	Personnel, Manpower & Training	CELMP16	George Graine	CELMP16	John Gorman	CHENG/L MP&T	134
APPLICATION STUDIES	Rob Req Study for Shipbrd Appl	003	George Gatlin	NSWC	Russ Werneth	Odetics	136
	ABR(X) Feasibility Design	05R14	Charles Lawson	05R14	Charles Lawson	Advanced Marine Enterprise	
	Robotics Dev in Supt of Nav Ops	90G	Bart Everett	90G	Bart Everett	SAIC	132

DIRECTORY OF FREQUENTLY USED ARPANET/MILNET ELECTRONIC MAIL ADDRESSES AND TELEPHONE NUMBERS

ORGANIZATION	ARPANET/MILNET	TELEPHONE
OFFICE OF NAVAL AQUISITION SUPPORT Washington D.C. 20360		
Jack McInnis (ONAS 064)	jmcinni@nswc-wo	(202) 692-0121
NAVAL SEA SYSTEMS COMMAND Washington, D.C. 20362		
LCDR Bart Everett (SEA 90G)	everett@dtrc	(202) 692-6118
Bill Butler (SEA 90G1)	bbutler@nosc	(202) 692-6118
John Freund (SEA 05R43)	freund@nems	(202) 692-8500
Roy Wells (SEA 070A)	wells@nswc-wo	(202) 692-7118
Garth Brown (SEA 06L1)		(202) 692-8118
Jon Fallick (SEA 05M2)	bleile@dtrc	(202) 692-0205
NAVAL EXPLOSIVE DISPOSAL TECHNOLOGY CENTER Indian Head, MD 20640		
John Butler	butler@nosc	(301) 743-4530
NAVAL SHIP ENGINEERING STATION Naval Base, Bldg. 501 Philadelphia, PA 19112		
Thom R. Galie	galie@nadc	(215) 952-7365
DAVID TAYLOR NAVAL SHIP R&D CENTER Bethesda, MD 20084		
Robert Jenkins(Code 1853)	jenkins@dtrc	(703) 227-1363
Joseph Sheehan (Code 1807)	sheehan@dtrc	(703) 227-1285
Kevin Scully (Code 1853)	scully@dtrc	(703) 227-1363
NAVAL OCEAN SYSTEMS CENTER San Diego, CA 92152		
Richard A. Gamble (Code 9302)	gamble@nosc	(619) 225-6457
Mike Dwyer (Code 9302)	dwyer@nosc	(619) 225-2727
Scott Y. Harmon (Code 4420)	harmon@usc-isi	(619) 225-2083
Douglas W. Gage (Code 8141)	gage@usc-isi	(619) 225-7183
John Silva (Code 0702)	silva@nosc	(619) 225-6564
Susan Alderson (Code 014)	suzie@nosc	(619) 225-2725
NAVAL SURFACE WEAPONS CENTER Silver Spring, MD 20903		
Russell Werneth (Code R402)	rwernet@nswc-wo	(301) 394-3088
Mary Lacey (Code R402)	mlacey@nswc-wo	(301) 394-2900
NAVAL RESEARCH LABORATORY Washington, D.C. 20375-5000		
Randy Shumaker	shumaker@nrl-aic	(202) 767-2884
APPLIED RESEARCH LABORATORY Pennsylvania State University P.O. Box 30 State College, PA 16804		
Henry Watson	hwatson@nswc-wo	(814) 865-6364
ROBOTICS AND ARTIFICIAL INTELLIGENCE DATABASE Computer Sciences Corporation 4045 Hancock Street San Diego, CA 92110		
Wayne H. Bostic	bostic@nosc	(619) 225-8401
Kathi Meyer	meyer@nosc	(619) 225-8401
SYSTEM ENHANCEMENT SERVICES COMPANY, INC. 1235 Jefferson Davis Highway Arlington, VA 22202		
Jon Lund	jlund@nswc-wo	(703) 920-7660
Charles Clark	cfclark@nswc-wo	(703) 920-7660